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NOTES ON THE DESIGN OF MICROSTRIP AND STRIPLINE BANDPASS FILTERS

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NOTES ON THE DESIGN OF MICROSTRIP AND STRIPLINE BANDPASS FILTERS

by

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SUMMARY

This paper describes the procedures used by the Microwave Integrated Circuit Group to design microstrip and stripline bandpass filters. Design computer programs are included together with worked examples. Comparisons between measured and theoretical responses for a number of practical filters are given.

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CONTENTS

1 INTRODUCTION

This paper describes the procedures used by the authors in the design of microstrip and stripline bandpass filters for microwave frequencies.

The basic objectives of this work were to (a) explore the possibility of using thick film techniques to produce microwave components, and (b) to provide a customer service supplying microwave components to RAE departments.

The thick film assessment was done in two parts. The first was concerned with an investigation into thick film microstrip losses and into how these losses are affected by process variables. This work has been published[1,2] in part and is the subject of an RAE report[3] which is in preparation at the present time. The second part of the thick film exercise involved the design and manufacture of a number of passive components, particularly filters. Two forms[4] of band-pass filter were investigated, one made up of edge-coupled half wavelength resonators, and the other made up of quarter wavelength short-circuited stubs and quarter wavelength connecting lines. Both Tchebyscheff and Butterworth responses were used.

While this work was taking place a number of stripline bandpass filters were designed for RAE customers. These were made using high quality printed circuit board.

In order to reduce the effort devoted to the repetitive arithmetic essential for filter design, and in order to let potential customers know promptly if their requirements are feasible, a number of computer programs were written. These programs are included in the following report together with an amended version of an existing NASA program[5].

Some examples of practical filters are presented, and a comparison is made between measured and theoretical responses. In general good agreement has been obtained.

2 MICROSTRIP AND STRIPLINE

2.1 Microstrip

Microstrip transmission line is well reported[6-8] and the basic structure is shown in Fig.1. It consists of a conducting strip of width W , and thickness h , separated from a conducting ground plane by dielectric material of thickness b , with dielectric constant ϵ_r.

Empirical equations[8] are given below which relate characteristic impedance Z_0, and velocity ratio (λ_g/λ_0), with physical dimensions and dielectric constant for microstrip.

$$Z_0 = \frac{377\ H}{\sqrt{\varepsilon_r}\ W\left[1 + 1.735\ \varepsilon_r^{-0.0724}\ (W/H)^{-0.836}\right]} \text{ ohm} \tag{1}$$

$$\frac{\lambda_g}{\lambda_0} = \left[\frac{1}{1 + 0.63\ (\varepsilon_r - 1)\ (W/H)^{0.1255}}\right]^{\frac{1}{2}} \tag{2}$$

for $W/H \geqslant 0.6$

$$\frac{\lambda_g}{\lambda_0} = \left[\frac{1}{1 + 0.6\ (\varepsilon_r - 1)\ (W/H)^{0.0297}}\right]^{\frac{1}{2}} \tag{3}$$

for $W/H \leqslant 0.6$

where λ_g = the wavelength in the line

λ_0 = the wavelength in air

W and H are in the same units.

An interactive computer program, called MICR, which is written in JEAN and can be used to produce tables of Z_0 and velocity ratio for various line widths, is listed in computer table 1. A worked example is given in Appendix A.

It should be noted that no account is taken of dispersion (i.e. change in substrate dielectric constant with frequency), and for the most accurate design the effective dielectric constant at the frequency of interest should be used.

2.2 Stripline

Stripline, often called triplate, is a transmission line constructed as shown in Fig.2. It consists of a conducting strip at the centre of two ground planes with the remainder of the volume between the ground planes filled with low loss dielectric material.

The characteristic impedance Z_0, of stripline is determined entirely by the physical dimensions of the line and the dielectric constant of the insulating material. A set of curves[9], derived by Cohn relating the characteristic impedance, the dielectric constant (ε_r) of the dielectric material and the dimensions of the stripline as depicted in Fig.2 are reproduced in Fig.3.

Tables of Z_0 for given dimensions and dielectric material may also be calculated from the following equations[10] to give results sufficiently accurate for engineering purposes.

For relatively broad strips, where $w/(b - t) \geq 0.35$

$$Z_0 = \frac{94.15}{\sqrt{\varepsilon_r}\left(\frac{w/b}{1 - t/b} + \frac{C_f'}{0.0885\varepsilon_r}\right)} \text{ ohm} \quad (4)$$

where w = the conductor strip width

t = the conductor strip thickness

b = the ground plane separation

w, t and b are in the same units

C_f' is the fringing capacitance in pF/cm from one corner of the strip to the adjacent ground plane and can be calculated from:

$$C_f' = \frac{0.0885\varepsilon_r}{\pi}\left[\left(\frac{2}{1 - t/b}\right)\log_e\left(\frac{1}{1 - t/b} + 1\right) - \left(\frac{1}{1 - t/b} - 1\right)\log_e\left(\frac{1}{(1 - t/b)^2} - 1\right)\right] \text{pF/cm} \quad \ldots\ldots(5)$$

For relatively narrow strips where $w/(b - t) \leq 0.35$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_r}}\log_e\left\{\frac{4b}{\frac{\pi w}{2}\left[1 + \frac{t}{\pi w}\left(1 + \log_e\frac{4\pi w}{t}\right) + 0.51\,(t/w)^2\right]}\right\} \text{ ohm} \quad . (6)$$

This equation is valid for $t/w < 0.11$.

The velocity ratio, which is independent of frequency and Z_0 in this case, is given by:

$$\text{velocity ratio} = \frac{1}{\sqrt{\varepsilon_r}} \quad . \quad (7)$$

A simple computer program, which can be used to produce tables relating strip width and characteristic impedance for given materials, is listed in computer table 2. The program, called STR2, uses equations (4), (5), (6) and (7) and is written in JEAN for interactive use. A worked example is given in Appendix B.

3 BANDPASS FILTER CONSIDERATIONS

3.1 General

Before designing a bandpass filter its response must be clearly defined.

Fig.4 shows a typical Butterworth, maximally flat, frequency response for a bandpass filter. In order to define the specification for such a filter using these programs, the following details are needed:

(i) the pass band edges f_1 , f_2 as defined by the 3dB points, or the centre frequency f_0 and the bandwidth Δf ;

(ii) a rejection, A_f in dB, at some frequency f_a , outside of the pass band.

In the case of a filter with a Tchebyscheff, equal-ripple response (see Fig.5) the details listed below must be known to define the specification:

(i) the maximum ripple R in dB which can be tolerated in the pass band;

(ii) the pass band edges f_1 , f_2 as defined by the ripple value, or the centre frequency f_0 and the bandwidth Δf .

(iii) an attenuation, A_f , in dB at some frequency, f_a , outside of the pass band.

With this information it is possible to determine the number of sections N , required to meet the specification, and also to obtain a theoretical response curve (assuming no losses) for the filter. A computer program, called PLOTBP, has been written for interactive use in BASIC, to determine N and give theoretical frequency-transducer gain plots for either Butterworth or Tchebyscheff responses. The program is listed in computer table 3 and a worked example is given in Appendix C.

The lowpass to bandpass mappings used in the program are given in Ref.4.

In order to complete a specification for a practical filter, it is necessary to specify the system characteristic impedance, Z_0 ohm , and the permissible insertion loss.

3.2 Dissipative losses

In practical filters the tuned elements will not be lossless, and this will show up mainly as insertion loss in the pass band. If the unloaded Q of

the resonators, Q_u, is known, an estimate of this loss can be made using the following equations[4]:

$$\text{dissipative midband loss} \simeq \frac{4.343}{W_f} \sum_{k=1}^{n} \frac{g_k}{Q_k} \text{ dB} \tag{8}$$

where W_f = the fractional bandwidth and is equal to $\Delta f/f_0$

n = the number of sections

g_k = the kth element of the equivalent lowpass prototype

Q_k = the unloaded Q of the kth resonator or section.

If the assumption is made that Q_k is the same for all values of k and is equal to Q_u, then a further approximation can be made so that:

$$\text{dissipative midband loss} \simeq \frac{4.343}{W_f Q_u} \sum_{k=1}^{n} g_k \text{ dB} \quad . \tag{9}$$

Provision for estimating the increase in midband loss due to dissipation is written into the program PLOTBP using equation (9) above.

3.3 Lumped element filters

Filters can be made using lumped components at microwave frequencies provided the components are kept small compared with a wavelength (typically less than 1/20 of a wavelength). The Plessey Co., under CVD Contract CRP9-137 is investigating lumped component filters with centre frequencies up to 2 GHz.

Fig.6 shows the layout of a lumped component bandpass filter together with its dual. Computer table 4 lists a program, written in BASIC, which can be used interactively to design filters of this type. The program is called BPLE and a worked example is given in Appendix D.

3.4 Parallel-coupled resonator filters

The filter[4,11] most commonly used is shown in Fig.7a. It consists of a number of edge- or parallel-coupled resonators which can be made in either microstrip or stripline. Each resonator is a half wavelength long and is coupled to its neighbour along half of its length.

Filters of this type are suitable for bandwidths of the order 2% to 25%. For bandwidths of less than 2%, dissipative insertion loss becomes excessive for many applications when using film circuit techniques. For bandwidths of greater than 25%, the gaps needed between the resonators to achieve the tight coupling become too narrow to fabricate.

In order to determine the physical dimensions of this type of filter, it is first necessary to compute the even- and odd-mode impedances, Z_{oe} and Z_{oo} respectively, for each coupled section. The even-mode impedance is the characteristic impedance of a single coupled line to ground, when equal currents are flowing in the two lines. The odd-mode impedance is the characteristic impedance of a single coupled line to ground, when equal and opposite currents flow in the two lines. Z_{oe} and Z_{oo} can be determined with the computer program BECFI, which is listed in computer table 5. The program is written in BASIC and is intended for interactive use. A worked example is shown in Appendix E.

3.4.1 Microstrip filter dimensions

The line widths and the gaps between the lines for the coupled sections can be obtained from the even- and odd-mode impedances by use of tables or curves, generated by a computer program written by Bryant and Weiss[12-14]. The dimensions of the input and output lines are determined as described in section 2.1.

Alternatively, a NASA computer program[5], which has been adapted to run on the RAE ICL 1904 computer, can be used to produce a complete design, when supplied with a specification for the filter and details of the microstrip materials. Firstly, it determines the number of sections to meet the specification, then Z_{oe} and Z_{oo} are calculated, and finally the physical dimensions are obtained. The program is written in FORTRAN. The modified version of the program, known as BDPS, is listed in computer table 6. A worked example together with full details for inputting data is given in Appendix F. It should be noted than some empirical adjustment of the lengths of the resonators is sometimes necessary to pull the filter onto frequency. This need for adjustment is due to a number of causes such as:

(i) fringing effects at the ends of the resonators;

(ii) insufficient data regarding the precise dielectric constant of the substrate material within a batch, or from batch to batch;

(iii) problems associated with the fact that the even- and odd-mode velocity ratios are different for microstrip.

3.4.2 Stripline filter dimensions

For stripline, the widths of the resonators and the gaps between them, as shown in Fig.7a, can be obtained for each coupled section by the use of nomograms[15] shown in Figs.8 and 9. The coupled lengths are given by:

$$L = \frac{3 \times 10^{10}}{4f_0 \sqrt{\epsilon_r}} \text{ cm} \tag{10}$$

where f_0 = the centre frequency in Hz,

ϵ_r = the dielectric constant of the dielectric material.

Because of fringing effects the resonators normally require shortening by a small amount $d\ell$ as shown in Fig.7b. It has been found, that for stripline the end correction recommended by Cohn[15] is adequate for most purposes. That is:

$$d\ell = 0.165\ b$$

where b = the ground plane separation.

The widths of the input and output lines are determined as described in section 2.2.

3.5 Short-circuited stub filters

This type of filter[4] (see Fig.10), which is also suitable for both microstrip and stripline, can be used for bandwidths of the order 30% to 120%.

In general the greater the bandwidth the narrower the stubs. Thus the maximum bandwidth which can be achieved is limited by the minimum stub width (i.e. the maximum characteristic impedance) which can be fabricated.

The use of excessively broad lines is not desirable because of the difficulty in establishing reference planes at T-junctions, and because of the risk of setting up spurious propagation modes at higher frequencies (e.g. a 20Ω microstripline should be usable only up to 15 GHz when made on 0.635mm alumina[16]). Hence, the maximum line width which can be tolerated sets the lower limit of bandwidth for the stub filter.

The lower limit of bandwidth can be extended a little by replacing the centre stubs, which are of approximately half the characteristic impedance of the end stubs, by pairs of stubs in parallel of double the desired characteristic impedance. This alternative layout is illustrated in Fig.10.

A computer program called STUB has been writted in BASIC to obtain the characteristic impedances of the stubs and connecting lines. It is intended for interactive use, and is listed in computer table 7. A worked example is given in Appendix G.

For a given filter, once the characteristic impedances are known, the physical dimensions for microstrip or stripline are obtained as described in sections 2.1 or 2.2 respectively.

4 PRACTICAL FILTERS

A number of practical filters, which were designed using the above procedures, are described in this section. Some were made in thick film, while others were made using printed circuit board.

4.1 Thick film filters

All of the thick film filters were constructed in microstrip using screen printing methods.

The filters were printed with Engelhard 9177 gold ink on 0.635mm, Coors ADS 995, alumina substrates. The conductor patterns were printed through 325 mesh, stainless steel screens. A firing temperature of 850°C was used throughout and to minimise cost, silver ground planes were used in each case. More detailed information on the manufacturing processes used are given in Ref.3. Connections at filter input and output ports were made *via* SMA coaxial to microstrip connectors.

(i) Filter A (see Fig.11)

Parallel-coupled resonators
Butterworth response
Two resonators
Centre frequency 1.52 GHz
5% bandwidth

As can be seen in Fig.11, this filter was folded in order to print it on a 50.8mm × 50.8mm substrate.

(ii) Filter B (see Fig.12)

Parallel-coupled resonators
Tchebyscheff response
0.1dB ripple
Three resonators
Centre frequency 3.0 GHz
13.4% bandwidth

(iii) Filter C (see Fig.13)

Parallel-coupled resonators
Tchebyscheff response
0.1dB ripple
Three resonators
Centre frequency 5.75 GHz
10% bandwidth

The worked example in Appendix F gives the design of this filter.

(iv) Filter D (see Fig.14)

Short-circuited $\lambda/4$ stubs with $\lambda/4$ connecting lines
Tchebyscheff response
0.01dB ripple
Five sections or stubs
Centre frequency 5 GHz
50% bandwidth

With this filter, the short circuits at the ends of the stubs were achieved by printing a conducting stripe along the ends of the stubs parallel to the edges of the substrate. These stubs were then connected to the ground plane by painting around the edge of the substrate with the same ink as was used for printing the conductors. The circuit was then fired in the normal way. The simplicity of achieving short circuits to ground by this method is a very useful feature of the thick film process.

Pairs of parallel stubs were used for the centre stubs as described in section 3.5.

This filter is the subject of the design example in Appendix G.

4.2 Printed circuit board filters

All of the filters described below were made using standard photo-etch techniques on high quality printed circuit board (Rexolite 2200 of 1.59mm thickness). This material was obtained plated on both sides with copper 0.036mm thick. Rexolite is a glass reinforced, cross-linked, styrene copolymer, which has a dielectric constant of 2.62 (10 MHz to 10 GHz).

Where filters were made in stripline, the conductor pattern was etched on one side of one sheet by photo-etch techniques leaving the copper ground plane on the other side. The copper on one side of a second sheet was completely removed and the whole structure was either glued together or clamped together using rows of screws. Occasionally aluminium backing plates were used to ensure even clamping over the total area of the filter. Type 'N' Esca launchers have been used on filters E, F, I and J while SMA connectors have been used on filters G and H.

(v) Filter E (see Fig.15)

Stripline
Parallel-coupled resonators
Butterworth response
Two resonators
Centre frequency 1.55 GHz
8% bandwidth

(vi) Filter F (see Fig.16)

Stripline
Parallel-coupled resonators
Butterworth response
Three resonators
Centre frequency 1.55 GHz
2½% bandwidth

Fig.16 shows the conductor pattern and also the complete assembly.

(vii) Filter G (see Fig.17)

Stripline
Parallel-coupled resonators
Butterworth response
Four resonators
Centre frequency 9.4 GHz
2½% bandwidth

This filter was assembled by gluing the two halves together using IS 12 Cyano-acrilate adhesive. This adhesive gives a strong bond for a thin, low rf loss glue line. It was necessary to solder copper foil around the edges of the filter, in order to make good electrical connection for rf between the two ground planes.

(viii) Filter H (see Fig.18)

Stripline
Parallel-coupled resonators
Butterworth response
Five resonators
Centre frequency 9.4 GHz
2½% bandwidth

(ix) Filter I (see Fig.19)

Stripline
Parallel-coupled resonators
Tchebyscheff response
0.5dB ripple
Five resonators
Centre frequency 850 MHz
23.5% bandwidth

In Fig.19 it can be seen that this filter was folded so that the resonators are V-shaped. This was done in order to reduce the overall length. The calculation of the even- and odd-mode impedances for this filter is the subject of the worked example in Appendix E.

(x) Filter J (see Fig.20)

Microstrip

$\lambda/4$ short circuited stubs with $\lambda/4$ connecting lines

Tchebyscheff response

0.1dB ripple

Four stubs

Centre frequency 1.5 GHz

60% bandwidth

At the end of each stub, it was found to be necessary to solder a copper plate between the stub and the ground plane to provide a good short-circuit to rf . The plate needed to be at least two stub widths wide and ideally stood above the plane of the surface of the printed circuit board to form a physical 'wall'.

4.3 Measurements

The transducer gain was measured for each of the filters over the desired frequency band, with a Hewlett Packard Network Analyser.

4.4 Theoretical performance

For each of the filters a theoretical response was calculated for comparison purposes.

For filters A, B, E to J a theoretical response assuming no losses was calculated as described in section 3.1. The worked example in Appendix C shows the determination of the theoretical performance of filter E.

For filter D a theoretical response was obtained by analysing the filter circuit on computer program[17], Redap 38. Realistic losses[3] per unit length for the filter lines were used in the analysis.

The theoretical response for filter C also takes into account filter losses. Here it was not possible to analyse the circuit directly, as the analysis program does not have provision to deal with coupled lines. In this case, the equivalent lumped circuit was designed as detailed in section 3.3. Equivalent[3] Q values were given to the lumped components, then this lumped circuit was analysed to give the theoretical response.

An estimate of mid-band loss for each filter was made using equation (9). The Q_u values used in equation (9) were obtained by direct measurement for 50Ω

thick film ring resonators[3]. The Rexolite values were obtained from the manufacturer's data sheet.

Fig.21 shows how Q_u varies with frequency for both 50Ω thick film, microstrip resonators and 50Ω, Rexolite 2200, stripline resonators.

5 RESULTS AND DISCUSSION

The measurement and theoretical responses of filters A to J are shown in Figs.22-31 respectively. A summary of the results is shown below.

Filter		Photograph Fig.No.	Frequency response Fig.No.	Q_u for 50Ω resonator	Mid-band loss dB		
					Measured	According to equation (9)	According to circuit analysis
Thick film	A	11	22	100	2.7	2.5	-
	B	12	23	150	1.0	0.7	-
	C	13	24	230	1.3	0.6	0.9
	D	14	25	210	0.9	0.2	0.25
Printed circuit board	E	15	26	320	1.2	0.5	-
	F	16	27	320	2.4	2.2	-
	G	17	28	390	2.0	2.3	-
	H	18	29	390	1.8	2.9	-
	I	19	30	230	1.5	0.7	-
	J	20	31	315	0.4	0.1	-

A feature of filters made up with distributed components is that spurious resonances will occur at multiples of the design centre frequency. This gives rise to spurious pass bands and the designer must bear this in mind from the start. In the case of the parallel-coupled resonator filter, the spurious pass bands occur when the resonators are $3\lambda g/2$, $5\lambda g/2$ etc (i.e. with centre frequencies of $3f_0$, $5f_0$ etc.). This effect is illustrated in Fig.32, which shows the frequency response of filter I over an extended frequency range.

6 CONCLUSIONS

(i) The design procedures described in this paper can be used to produce satisfactory filters with centre frequencies from 1.5 to 5.75 GHz for thick film, and with centre frequencies of 0.85 to 9.4 GHz for Rexolite 2200. There

is no indication that an upper limit in frequency has been reached for either technology. Only lack of time and suitable requirements have prevented work at higher frequencies than those reported.

(ii) The measured frequency responses match quite closely in every case the theoretical responses obtained from computer program PLOTBP.

(iii) It should be stressed that the method used to predict mid-band loss is not accurate, particularly with the assumption that all of the resonators will have the same Q_u value as that of a 50Ω resonator. However, if this is accepted, it is still a very useful way of obtaining a rough estimate of mid-band loss sufficiently accurate to decide in most cases whether a filter design is feasible or not.

(iv) All of the interactive programs have been written in such a manner, that they can be run by personnel with the absolute minimum of training in computer operation.

Acknowledgments

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SYMBOLS

W	width of microstripline conductor
h	thickness of microstripline conductor
H	dielectric thickness for microstripline
ϵ_r	dielectric constant
Z_0	transmission line characteristic impedance in ohm
λ_g	wavelength in transmission line
λ_0	wavelength in air
w	width of stripline conductor
t	thickness of stripline conductor
b	stripline ground plane separation
C_f'	fringing capacitance in pF/cm
f_1	frequency of lower edge of pass band
f_2	frequency of upper edge of pass band
f_0	centre frequency of pass band
Δf	bandwidth
A_f	attenuation in dB
f_a	frequency where A_f is required
R	Tchebyscheff ripple value in dB
N	number of filter sections
Q	resonator quality factor
Q_u	unloaded Q value
W_f	fractional bandwidth
n	number of filter sections
$g_1, g_2 \cdots$	elemental values of the equivalent lowpass prototype
Z_{oe}	even-mode impedance of coupled transmission lines
Z_{oo}	odd-mode impedance of coupled transmission lines
L	length of coupled region for parallel-coupled resonators
$d\ell$	resonator end correction

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17	Redac Software Ltd	Redap 38 Microwave circuit analysis program. (Redacal Version)

Table 1

Computer Table 1   Listing of computer program MICR

```
1.1 TYPE "(PROG: MICR)"
1.2 LINE,2 TIMES
1.24 DEMAND E AS"ENTER DIELECTRIC CONSTANT"
1.25 DEMAND P AS"ENTER SUBSTRATE THICKNESS(MM)"
1.29 TYPE"ENTER LOWEST(L),INCREMENT(I) & HIGHEST(H) VALUES OF WIDTH(MM)"
1.3 DEMAND L,I,H
1.39 LINE, 4 TIMES
1.4 TYPE" W(MM)    W(THOU)   Z0(OHMS) L(G)/L(O)"
1.41 LINE
1.42 N=0
1.5 DO PART 2 FOR W=L(I)H
2.05 S=W/P
2.1 A=1/(S↑0.336)
2.15 B=1/(E↑0.0724)
2.2 C=1+(A*B*1.735)
2.25 D=C*SQRT(E)
2.3 Z=377/(S*D)
2.9 TO PART 3 IF S>.6
2.92 DO PART 4
3.1 L=SQRT(1/(1+0.63*(E-1)*S↑0.1255))
3.2 DO PART 5
4.1 L=SQRT(1/(1+0.6*(E-1)*S↑0.0297))
4.2 DO PART 5
5.2 T=W*1000/25.4
5.21 N=N+1
5.3 TYPE W,T,Z,L IN FORM 1
5.4 DO PART 6 IF FP(N/10)<0.05
6.1 LINE
6.2 DO PART 7 IF FP(N/40)<0.0001
7.1 LINE, 4 TIMES
FORM1:
###.###  ###.###  ###.###    #.####
****
```

Table 2

Computer Table 2 Listing of computer program STR2

```
1.1 TYPE "(PROG: STR2)"
1.3 DO PART 2
2.1 DEMAND E AS"ENTER DIELECTRIC CONSTANT"
2.11 DEMAND T AS"ENTER CONDUCTOR THICKNESS(MM)"
2.111 DEMAND B AS"ENTER GROUND PLANE SEPARATION(MM)"
2.12 TYPE"ENTER LOWEST(L),INCREMENT(I),HIGHEST(H) VALUES OF WIDTH(MM)"
2.13 DEMAND L,I,H
2.15 LINE,4 TIMES
2.2 U=1/SQRT(E)
2.25 TYPE U IN FORM 1
2.3 LINE
2.35 TYPE " W(MM)  W(THOU) W/(B-T)  Z(OHMS)"
2.4 LINE
2.45 Q=0
2.5 DO PART 3 FOR W=L(I)H
3.1 TO  PART 4 IF W/(B-T)<.35
3.15 A=(1-(T/B))
3.2 D=(2/A)*LOG((1/A)+1)
3.25 F=((1/A)-1)*LOG((1/A↑2)-1)
3.3 C=(1/PI)*(D-F)
3.35 G=(((W/B)/A)+C)
3.4 Z=94.15/(SQRT(E)*G)
3.45 DO PART 5
4.1 A=1+LOG((4*PI*W)/T)
4.15 A=1+((T/(PI*W))*A)+(0.51*((T/B)↑2))
4.2 D=(W/2)*A
4.25 Z=(60/SQRT(E))*LOG((4*B)/(D*PI))
4.3 DO PART 5
5.1 V=W*1000/25.4
5.15 X=W/(B-T)
5.2 Q=Q+1
5.25 LINE IF FP(Q/10)<0.05
5.3 LINE, 3 TIMES IF FP(Q/40)<0.0001
5.35 TYPE W,V,X,Z IN FORM 2
FORM1:
VELOCITY RATIO=#.###
FORM2:
##.###  ###.###  #.###  ###.###
****
```

Computer Table 3 Listing of computer program PLOTBP

```
NEW PLOTBP
1 DIM A(26),B(26),G(26)
4 I=2.7183
5 J1=3.14159
6 PRINT"BAND-PASS FILTERS WITH TCHEBYSCHEFF OR BUTTERWORTH RESPONSES"
7 PRINT"ENTER ALL FREQUENCIES IN HZ"
8 PRINT"ENTER 1 TO SPECIFY BAND EDGES: 0 FOR"
9 PRINT"CENTRE FREQ & FRACTIONAL BANDWIDTH"
10 INPUT T3
12 IF T3=0 THEN 25
15 PRINT"ENTER FREQ OF LOWER & UPPER BAND-EDGE PTS"
20 INPUT F1,F2
21 B=(F1+F2)/2
22 W=(F2-F1)/B
23 GOTO 31
25 PRINT"ENTER CENTRE FREQ & FRACTIONAL  BANDWIDTH"
26 INPUT B,W
27 F1=(B/2)*(2-W)
28 F2=(B/2)*(2+W)
29 PRINT"F1=";F1;"        F2=";F2
31 P1=100*W
32 PRINT"BANDWIDTH=";P1;"%        F(0)=";B;"HZ"
33 PRINT"ENTER REQD REJ(DB) & FREQ WHERE THIS IS REQD"
34 INPUT R,F3
35 PRINT"ENTER 1 FOR TCHEBYSCHEFF: 0 FOR BUTTERWORTH"
36 INPUT T1
37 IF T1=0 THEN 650
45 S(1)=0.01
50 S(2)=0.1
55 S(3)=0.2
60 S(4)=0.5
65 S(5)=1
70 S(6)=2
75 S(7)=3
85 P=0
90 P=P+1
95 N=0
100 N=N+1
105 IF N>15 THEN 165
110 S8 =S(P)
115 E=10↑(S8/10)-1
116 GOSUB 2000
130 A=N*LOG(SQR((C+SQR((C↑2)-1))↑2))
135 L=(I↑A+1/I↑A)/2
140 D=(10/2.30258)*LOG(1+(E*(L↑2)))
145 IF D<R THEN 100
150 PRINT"N=";N;"TOR LOSS=";D;"DB AT";F3;"HZ FOR";S8;"DB RIPPLE"
155 IF S8<>S(7) THEN 90
160 GOTO 195
165 PRINT"MORE THAN 15 ELEMENTS REQD FOR RIPPLE OF";S8;"DB"
170 IF S8<>S(7) THEN 90
195 PRINT"IS PLOT REQD? ENTER 1 FOR YES: 0 FOR NO"
200 INPUT T4
205 IF T4=0 THEN 9999
290 PRINT"ENTER NO. OF ELEMENTS,RIPPLE(DB)"
291 PRINT"& FRACTIONAL BANDWIDTH"
292 INPUT N,S3,W
```

Table 3 cont'd

```
293 E=10↑(S8/10)-1
295 GOSUB 980
490 FOR G=F4TOF5 STEP F6
491 IF G=B THEN 493
492 GOTO 495
493 D=0
494 GO TO 520
495 LET F3=G
496 GOSUB 2000
502 IF C↑2<1 THEN 507
503 H=N*LOG(SQR((C+SQR((C↑2)-1))↑2))
504 L=(I↑H+1/I↑H)/2
505 D=(10/2.30258)*LOG(1+(E*(L↑2)))
506 GOTO 520
507 Q=SQR(1-(C↑2))
508 Q=N*ATN(Q/C)
509 D=(10/2.30258)*LOG(1+(E*(COS(Q)↑2)))
520 PRINT G
521 GOSUB 1500
522 NEXT G
523 GOSUB 1200
524 IF T3=0 THEN 615
525 GOSUB 1400
526 GOSUB 2200
615 PRINT"IS ANOTHER PLOT REQD? ENTER 1 FOR YES: 0 FOR NO"
620 INPUT T5
625 IF T5=0 THEN 9999
630 GOTO 290
650 N=0
655 N=N+1
660 IF N>15 THEN 695
665 GOSUB 2000
670 E=10↑0.3-1
675 D=(10/2.30258)*LOG(1+E*C↑(2*N))
680 IF D<A THEN 655
685 PRINT"N=";N;"        TRANSDUCER LOSS=";D;"DB AT";F3;"HZ"
690 GOTO 705
695 PRINT"MORE THAN 15 ELEMENTS REQD"
705 PRINT"IS PLOT REQD? ENTER 1 FOR YES: 0 FOR NO"
710 INPUT T2
715 IF T2=0 THEN 9999
720 PRINT"ENTER NO. OF ELEMENTS,& FRACTIONAL BANDWIDTH"
725 INPUT N,W
730 GOSUB 980
735 FOR G=F4TOF5 STEP F6
740 IF G=B THEN 750
745 GOTO760
750 D=0
755 GOTO 770
760 LET F3=G
761 GOSUB 2000
765 D=(10/2.30258)*LOG(1+E*C↑(2*N))
770 PRINT G
775 GOSUB 1500
780 NEXT G
781 GOSUB 1200
782 IF T3=0 THEN 7[illegible]
783 GOSUB 1305
784 GOSUB 2200
785 PRINT"IS ANOTHER PLOT REQD? ENTER 1 FOR YES: 0 FOR NO"
790 INPUT T2
795 IF T2=0 THEN 9999
800 GOTO 720
980 PRINT"Y-AXIS:ENTER MIN,MAX,INC FOR FREQ"
985 INPUT F5,F4,F6
990 PRINT"X-AXIS:ENTER MAX ATTENUATION(DB)"
995 INPUT A
1000 PRINT TAB(25);"TRANSDUCER GAIN(DB)"
```

Table 3 concl'd

```
1005 FOR K=0TO5
1010 Y1=K*A/5
1012 Y1=-Y1
1015 PRINT TAB(18+10*K);Y1;
1020 NEXT K
1025 PRINT
1030 PRINT TAB(20);"!";
1035 FOR K=1TO50
1040 IF K/10=INT(K/10) THEN 1050
1045 GOTO 1060
1050 PRINT"!";
1055 GOTO 1065
1060 PRINT".";
1065 NEXT K
1066 PRINT" FREQ   GAIN"
1067 PRINT
1068 F6=-F6
1070 RETURN
1200 PRINT"IS APPROX Q OF RESONATORS KNOWN?"
1205 PRINT"ENTER 1 FOR YES: 0 FOR NO"
1210 INPUT T3
1215 IF T3=0 THEN 1230
1220 PRINT"ENTER APPROX VALUE OF UNLOADED Q OF RESONATORS"
1225 INPUT U2
1230 RETURN
1305 FOR K=1TON
1310 G(K)=2*SIN(((2*K-1)*J1)/(2*N))
1315 NEXT K
1320 RETURN
1400 X1=S8/17.37
1405 M=LOG((I↑X1+I↑(-X1))/(I↑X1-I↑(-X1)))
1410 Y=M/(2*N)
1415 V=M/4
1420 Q=(I↑Y-I↑(-Y))/2
1425 FOR K=1TON
1430 A(K)=SIN(((2*K-1)*J1)/(2*N))
1435 B(K)=(Q↑2)+((SIN((K*J1)/N))↑2)
1440 NEXT K
1445 G(1)=2*A(1)/Q
1450 FOR K=2TON
1455 G(K)=(4*A(K-1)*A(K))/(B(K-1)*G(K-1))
1460 NEXT K
1485 RETURN
1500 M=INT(D*50/A)
1505 IF M>50 THEN 1525
1510 IF M=0  THEN 1535
1515 PRINT TAB(6);D;TAB(20);".";TAB(20+M);"+"
1520 GOTO 1540
1525 PRINT TAB(6);D;TAB(20);"."
1530 GOTO 1540
1535 PRINT TAB(6);D;TAB(20);"+"
1540 RETURN
2000 J2=1-W/2
2005 J3=(J1*F3)/(2*B)
2010 J4=(J1/2)*J2
2015 V1=(SQR((SIN(J4))↑2))↑(1/N)
2020 V2=(SQR((SIN(J3))↑2))↑(1/N)
2025 C=((-COS(J3))*V1)/((COS(J4))*V2)
2030 RETURN
2200 U1=0
2205 FOR K=1TON
2210 U1=U1+G(K)
2215 NEXT K
2220 U1=(4.343*J1)/(W*J2)
2225 PRINT"MIDBAND LOSS INCREASE DUE TO DISSIPATION=";U1;"DB APPROX"
2230 RETURN
9999 END
```

Table 4

Computer Table 4 Listing of computer program BPLE

```
NEW BPLE
1 DIM A(26),B(26),C(26),G(26),L(26)
3 PRINT"LUMPED-ELEMENT BAND-PASS FILTERS"
4 PRINT"DO NOT USE EVEN NOS OF SECTIONS"
5 PRINT"FOR TCHEBYSCHEFF RESPONSE"
6 PRINT"ENTER NOS OF SECTIONS,Z(OHMS),CENTRE FREQ(HZ),"
7 PRINT"AND FRACTIONAL BANDWIDTH"
8 INPUT N,Z,F,W
9 E=2.7183
10 P1=3.1416
11 X=2*P1*F
12 G(0)=1
14 PRINT"ENTER 1 FOR TCHEBYSCHEFF; 0 FOR BUTTERWORTH"
15 INPUT T1
16 IF T1=1 THEN 19
17 GOSUB 1300
18 GOTO 20
19 GOSUB 1000
20 FOR K=0 TO (N+1)
21 PRINT"G(";K;")=";G(K)
22 NEXT K
41 PRINT
42 PRINT"SOURCE AND LOAD IMPEDANCE=";Z;"OHMS"
45 FOR K=1 TO N
46 P=K/2-INT(K/2)
50 IF P>0.1 THEN 60
52 C(K)=W/(Z*G(K)*X)
54 L(K)=(Z*G(K))/(W*X)
56 PRINT"C(";K;")=";C(K);"F       L(";K;")=";L(K);"H"
57 GOTO 63
60 C(K)=G(K)/(W*Z*X)
61 L(K)=(W*Z)/(G(K)*X)
62 PRINT"C(";K;")=";C(K);"F       L(";K;")=";L(K);"H"
63 NEXT K
64 PRINT"C(1)L(1);C(3)L(3)....PARALLEL TUNED"
65 PRINT"C(2)L(2);C(4)L(4)....SERIES TUNED"
76 PRINT
77 PRINT
78 PRINT"FOR DUAL"
85 FOR K=1 TO N
86 P=K/2-INT(K/2)
90 IF P>.1 THEN 100
92 C(K)=G(K)/(W*Z*X)
94 L(K)=(W*Z)/(G(K)*X)
96 PRINT"C(";K;")=";C(K);"F       L(";K;")=";L(K);"H"
97 GOTO 103
100 L(K)=(Z*G(K))/(W*X)
101 C(K)=W/(Z*G(K)*X)
102 PRINT"C(";K;")=";C(K);"F       L(";K;")=";L(K);"H"
103 NEXT K
104 PRINT"C(1)L(1);C(3)L(3)....SERIES TUNED"
105 PRINT"C(2)L(2);C(4)L(4)....PARALLEL TUNED"
106 PRINT"IS ANOTHER DESIGN REQD?"
107 PRINT"ENTER 1 FOR YES; 0 FOR NO"
108 INPUT T2
109 IF T2=1 THEN 6
110 GOTO 9999
1000 PRINT"ENTER RIPPLE VALUE(DB)"
```

Table 4 cont'd

```
1005 INPUT R
1007 PRINT"TCHEBYSCHEFF ELEMENTAL VALUES"
1010 X1=R/17.37
1015 M=LOG((E↑X1+E↑(-X1))/(E↑X1-E↑(-X1)))
1020 Y=M/(2*N)
1021 V=M/4
1025 Q=(E↑Y-E↑(-Y))/2
1030 FOR K=1TON
1035 A(K)=SIN(((2*K-1)*P1)/(2*N))
1040 B(K)=(Q↑2)+((SIN((K*P1)/N))↑2)
1045 NEXT K
1050 G(1)=2*A(1)/Q
1055 FOR K=2TON
1060 G(K)=(4*A(K-1)*A(K))/(B(K-1)*G(K-1))
1065 NEXT K
1066 IF((N/2)-INT(N/2))>0.4 THEN 1069
1067 G(N+1)=((E↑V+E↑(-V))/(E↑V-E↑(-V)))↑2
1068 GOTO 1070
1069 G(N+1)=1
1070 RETURN
1300 PRINT"BUTTERWORTH ELEMENTAL VALUES"
1301 G(N+1)=1
1305 FOR K=1TON
1310 G(K)=2*SIN(((2*K-1)*P1)/(2*N))
1315 NEXT K
1320 RETURN
9999 END
```

Table 5

Computer Table 5 Listing of computer program BECFI

```
NEW BECFI
1 DIM A(26),B(26),G(26),J(26)
2 PRINT"EDGE-COUPLED BAND-PASS FILTERS"
6 PRINT"ENTER NOS OF SECTIONS,Z(OHMS) AND FRACTIONAL BANDWIDTH"
7 INPUT N,Z,W
9 E=2.7183
10 P1=3.1416
12 G(0)=1
14 PRINT"ENTER 1 FOR TCHEBYSCHEFF; 0 FOR BUTTERWORTH"
15 INPUT T1
16 IF T1=1 THEN 19
17 GOSUB 1300
18 GOTO 20
19 GOSUB 1000
20 FOR K=0TO(N+1)
21 PRINT"G(";K;")=";G(K)
22 NEXT K
23 PRINT
41 PRINT"SOURCE AND LOAD IMPEDANCE=";Z;"OHMS"
45 PRINT"ZOE(OHMS)";TAB(13);"ZOO(OHMS)";TAB(30);"C";TAB(40);"CF(DB)"
42 PRINT
50 FOR K=0TON
60 IF K=0 THEN 200
70 IF K=N THEN 200
80 J(K)=(P1*W)/(2*SQR(G(K)*G(1+K)))
82 Z1=(1+J(K)+(J(K)↑2))*Z
84 Z2=(1-J(K)+(J(K)↑2))*Z
86 C=((Z1/Z2)-1)/((Z1/Z2)+1)
88 D=-(20/2.30258)*LOG(1/C)
90 L=K+1
120 PRINT Z1;TAB(13);Z2;TAB(26);C;TAB(39);D;TAB(52);"S(";K;",";L;")"
130 NEXT K
140 GOTO 250
200 J(K)=SQR((P1*W)/(2*G(K)*G(K+1)))
210 GOTO 82
250 PRINT "IS ANOTHER DESIGN REQD ? ENTER 1 FOR YES; 0 FOR NO"
260 INPUT T2
270 IF T2=1 THEN 6
280 GOTO 9999
1000 PRINT"ENTER RIPPLE VALUE(DB)"
1005 INPUT R
1007 PRINT"TCHEBYSCHEFF ELEMENTAL VALUES"
1010 X1=R/17.37
1015 M=LOG((E↑X1+E↑(-X1))/(E↑X1-E↑(-X1)))
1020 Y=M/(2*N)
1021 V=M/4
1025 Q=(E↑Y-E↑(-Y))/2
1030 FOR K=1TON
1035 A(K)=SIN(((2*K-1)*P1)/(2*N))
1040 B(K)=(Q↑2)+((SIN((K*P1)/N))↑2)
1045 NEXT K
1050 G(1)=2*A(1)/Q
1055 FOR K=2TON
1060 G(K)=(4*A(K-1)*A(K))/(B(K-1)*G(K-1))
1065 NEXT K
1066 IF((N/2)-INT(N/2))>0.4 THEN 1069
1067 G(N+1)=((E↑V+E↑(-V))/(E↑V-E↑(-V)))↑2
1068 GOTO 1070
1069 G(N+1)=1
1070 RETURN
1300 PRINT"BUTTERWORTH ELEMENTAL VALUES"
1301 G(N+1)=1
1305 FOR K=1TON
1310 G(K)=2*SIN(((2*K-1)*P1)/(2*N))
1315 NEXT K
1320 RETURN
9999 END
```

Computer Table 6 Listing of computer program BDPS

```
      NO LIST
      PROGRAM(BDPS)
      INPUT 1=CRO
      OUTPUT 3=LPO
      TRACE 2
      END
      MASTER BANDPASS
      REAL GVALUE(30),WIDTH(30),LENGTH(30),GAP(30)
     P      ZOO(30),ZOE(30),LAMBDA
          LIST/CONST/ZO,DIEK,H,BAND,CENTER
        MELIST/DONST/RIPPLE.SECTN,FREQ,ATTEN
    1 READ(1,CONST)
      READ(1,DONST)
      CONV=25 4001
      H=H/CONV
      BANDF=BAND/CENTER
      IF(BAND) 5,5,25
    5 BERR=156.*BANDF*BANDF
      BAND=-BAND
      IF(RIPPLE)20,20,10
   10 BERR=125.*BERR/156.
   20 BANDF=-BANDF*(1.+BERR/100.)
   25 NSECT=SECTN
      IF(NSECT)30,30,50
   30 FNORM=ABS(FREQ-CENTER)/CENTER/(BANDF/2.)
      CALL NSECTN(NSECT,FNORM,ATTEN,RIPPLE,IER)
      IF(IER)50,50,40
   40 WRITE(3,910)FREQ,ATTEN,RIPPLE
  910 FORMAT( // 32H DATA INCOMPLETE OR INCONSISTENT,12H ATTEN FREQ=,F7.
     13,7H ATTEN=,F6.2,8H RIPPLE=,F5.2, // )
      GO TO 160
   50 CALL ELEMENT(GVALUE,NSECT,RIPPLE,IER)
      IF(IER)70,70,60
   60 WRITE(3,920)
  920 FORMAT( //,36H ERROR IN ELEMENT VALUE COMPUTATIONS,// )
      GO TO 160
   70 TERM=(DIEK-1.)*(.2258+.1208/DIEK)/(DIEK+1.)
      TERM=ALOG(1.3/8.+SQRT(64./(1.3*1.3)+2.))-TERM
      IF(TERM)80,90,90
   80 WRITE(3,930)
  930 FORMAT( // 30H FRINGING FIELD CAPACITY ERROR, // )
      GO TO 160
   90 ZAIR=59.96*ALOG(4./1.3+SQRT(16./(1.3*1.3)+2.))
      Z=84.7833*TERM/SQRT(1.+DIEK)
      CF=(ZAIR/(.011803*Z*Z)-.225*1.3*DIEK)/2.
      N=NSECT+1
      TEMP=3.141592654*BANDF/2.
      DO 100 I=1,N
      TERM=TEMP/SQRT(GVALUE(I)*GVALUE(I+1))
      IF(I-1)100,104,102
  102 IF(I-N)106,104,100
  104 TERM=TERM/SQRT(TEMP)
  106 ZOE(I)=1.+TERM*TERM
      ZOO(I)=(ZOE(I)-TERM)*ZO
      ZOE(I)=(ZOE(I)+TERM)*ZO
      LENGTH(I)=0.
```

Table 6 cont'd

```
      WIDTH(I)=0.
  100 GAP(I)=0.
      LAMBDA=11.803/CENTER/4.
      IER1=0
      DO 130 I=1,N
      CALL CPLMS(WIDTH(I),GAP(I),DODD,DEVEN,H,DIEK,ZOO(I),ZOE(I),IER)
      IF(IER)110,120,105
  105 WRITE(3,940)
  940 FORMAT( // ,33H ERROR IN COUPLED STRIP SYNTHESIS, // )
      GO TO 160
  110 IER1=IER1+1
  120 W=WIDTH(I)/H
      LENGTH(I)=LAMBDA/SQRT((DODD+DEVEN)/2.)
      CALL ZSTRIP(Z,W,DIEK)
      ZAIR=59.96*ALOG(4./W+SQRT(16./(W*W)+2.))
      CAP=ZAIR/(.011803*Z*Z)
      LENGTH(I)=LENGTH(I)-CF*WIDTH(I)/CAP
  130 CONTINUE
      CALL MSTRIP(ZO,DIEK,H,W,C,IER)
      BANDF=BANDF*CENTER
      IF(IER-1)150,135,140
  135 WRITE(3,950)
  950 FORMAT( // 44H ERROR IN INPUT DATA-NEGATIVE OR ZERO VALUES, // )
      GO TO 160
  140 IER1=IER1+1
  150 WRITE(3,960)CENTER,BAND,RIPPLE,NSECT,H,DIEK,ZO,W,BANDF
  960 FORMAT(1H1,///,10X,35H PARALLEL COUPLED MICROSTRIP FILTER,// F7.3,
     121H GHZ CENTER FREQUENCY,F7.3,14H GHZ BANDWIDTH, / F7.3,10H DB RIP
     2PLE,11X,I7,9H SECTIONS, / F7.3,15H INCH SUBSTRATE,6X,F7.3,20H DIEL
     3ECTRIC CONSTANT, / F5.1,35H OHM MICROSTRIP INPUT LINE OF WIDTH,F8.
     44,7H INCHES, / F7.3,38H GHZ BANDWIDTH DUE TO PRE-COMPENSATION, / )
      WCONV=W*CONV
      WRITE(3,222)ZO,WCONV
 222  FORMAT(1H ,F5.1,21H OHM INPUT LINEWIDTH=,F8.4,3H MM)
      WRITE(3,970)
  970 FORMAT( / 54H SEC ELEMENT    WIDTH      GAP    LENGTH      ZOO      ZO
     1E, / 54H NUM  VALUE    INCHES    INCHES   INCHES      OHMS     OHMS,/ )
      DO 254 I=1,N
      J=I-1
  152 WRITE(3,980)J,GVALUE(I),WIDTH(I),GAP(I),LENGTH(I),ZOO(I),ZOE(I)
  980 FORMAT(I3,3F9.4,F8.3,2F8.2)
      WIDTH(I)=WIDTH(I)*CONV
      GAP(I)=GAP(I)*CONV
      LENGTH(I)=LENGTH(I)*CONV
 254  WRITE(3,52)WIDTH(I),GAP(I),LENGTH(I)
  52  FORMAT(1H ,3HW =,F9.4,2HMM/1H ,3HS =,F9.4,2HMM/
     11H ,3HL =,F9.4,2HMM///)
      WRITE(3,982)
  982 FORMAT( /// ,1H1 )
      IF(IER1)155,1,155
  155 WRITE(3,985)
  985 FORMAT( // 45H ACCURACY OF MICROSTRIP SYNTHESIS IS IN DOUBT, // )
  160 WRITE(3,990)
  990 FORMAT( // 29H DESIGN ABORTED DUE TO ERRORS,  ///// )
      GO TO 1
      END
      SUBROUTINE CPLMS(W,S,DODD,DEVEN,H,DIEK,ZOO,ZOE,IER)
      IER=0
      H1=1.
      S=1.05
      S1=.9
      ICOUNT=0
      Z1=ZOE+ZOO
      CPLING=(ZOE-ZOO)/Z1
      Z1=Z1/2.
   10 ICOUNT=ICOUNT+1
```

Table 6 cont'd

```
      IF(ICOUNT-20)20,20,60
   20 Z=Z1
      IF(S-1.)30,40,40
   30 Z=Z1/(1.-0.03125*(1.-S)*W)
   40 CALL MSTRIP(Z,DIEK,H1,W,D999,IER)
      W=W*(1.+.0008/(W*W))
      CALL INVCPL(S1,CPLING,W,DIEK,IER)
      IF(ABS(S-S1)/S-.001)70,70,50
   50 S=S1
      GO TO 10
   60 IER=-2+IER
   70 AIR=1.0
      CALL ZSTRIP(ZOAIR,W,AIR)
      TEMP=ZOAIR*Z1/Z
      TEMP1=.05*(1.-S1*S1/20.)
      IF(TEMP1)80,90,90
   80 TEMP1=0
   90 S=S1*H
      TEMP2=(4.89+20.*W*W)/(4.397+20.*W*W)
      W=W*H
      DODD=(1.-CPLING-TEMP1)*TEMP/ZOO
      DEVEN=(1.+CPLING+TEMP1)*TEMP/ZOE
      DODD=DODD*DODD*TEMP2
      DEVEN=DEVEN*DEVEN
      RETURN
      END
      SUBROUTINE INVCPL(S,CPLING,W,DIEK,IER)
      TARGET=1./CPLING-1.
      A=1.482
      B=.18
      C=4.37
      D=1.40468
      E=100.
      ICOUNT=0
   10 ICOUNT=ICOUNT+1
      IF(ICOUNT-20)20,20,50
   20 S1=S+B*(W-1.5)
      TERM1=A*S1*S1+C*S1+D
      TERM2=1.+S/(E*W)
      TRIAL=TERM1*TERM2-TARGET
      DERIV=TERM1/(E*W)+TERM2*(2.*A*S1+C)
      IF(ABS(TRIAL)/TARGET-.0001)60,60,30
   30 S=S-TRIAL/DERIV
      IF(S-.01)40,10,10
   40 S=.01
      GO TO 10
   50 IER=-1
   60 S=S/(1.+.0009/(S*W*W))
      RETURN
      END
      SUBROUTINE ZSTRIP(Z,W,DIEK)
      IF(W-1.3)1,1,2
    1 TERM=(DIEK-1)/(DIEK+1)
      TERM=TERM*(.2258+.1208/DIEK)
      TERM=ALOG(W/8.+SQRT(64./W/W+2.))-TERM
      Z=84.7833/SQRT(DIEK+1.)*TERM
      RETURN
    2 X=2.
      PI=3.1415926
    3 F=X/PI-1./X/PI-2./PI*ALOG(X)-W
      IF(ABS(F)-.0001)5,5,4
    4 X=X-F*PI/(1.-1./X)**2
      GO TO 3
    5 A=ALOG(X)
      D=1.+(X+1./X)/2.
      R=PI*188.35/D
```

Table 6 cont'd

```
      S1=.179*(X+1./X)+.953
      S1=.732*(A-ALOG(S1+SQRT(S1*S1-1.)))
      S2=.3863-1./X
      S=S2+(S1-S2)/DIEK
      TERM=DIEK-(DIEK-1)*(A-S)/D
      Z=R/SQRT(TERM)
      RETURN
      END
      SUBROUTINE NSECTN(SECTS,FREQ,ATTEN,RIPPLE,IER)
      INTEGER SECTS
      IER=0
C
C     TEST FOR VALID DATA
C
      IF(ATTEN)10,10,20
   10 IER=1
      RETURN
   20 IF(FREQ)10,10,30
C
C     CHECK FOR FILTER TYPE
C
   30 IF(RIPPLE)10,40,50
C
C     MAX FLAT FILTER
C
   40 TEMP=ALOG(10.**(ATTEN/10.)-1.)/(2.*ALOG(FREQ))
      GO TO 80
C
C     CHEBYSHEV FILTER
C
   50 CONST=2.302585
      TEMP=EXP(CONST*RIPPLE/10.)-1.
      TEMP=SQRT((EXP(CONST*ATTEN/10.)-1.)/TEMP)
      IF(FREQ-1.)60,70,70
   60 TEMP=ATAN(SQRT(1./(TEMP*TEMP)-1.))
      TEMP=TEMP/ATAN(SQRT(1./(FREQ*FREQ)-1.))
      GO TO 80
   70 TEMP=ALOG(TEMP+SQRT(TEMP*TEMP-1.))
      TEMP=TEMP/ALOG(FREQ+SQRT(FREQ*FREQ-1.))
   80 SECTS=IFIX(TEMP+.999)
C
C     MUST HAVE AT LEAST TWO SECTIONS
C
      IF(SECTS-1)90,90,100
   90 SECTS=2
  100 CONTINUE
      RETURN
      END
      SUBROUTINE ELEMENT(GVALUE,SECTS,RIPPLE,IER)
C
C     G0=GVALUE(1),G1=GVALUE(2),ETC
C
      INTEGER SECTS
      REAL RIPPLE,GVALUE(30)
      SINHF(X)=EXP(X)-EXP(-X)
      COSHF(X)=EXP(X)+EXP(-X)
C
C     TEST NUMBER OF SECTIONS
C
      IF(SECTS-1)10,10,20
   10 IER=1
      RETURN
   20 PI=3.141592654
      TEMP=FLOAT(SECTS)
      N=SECTS+1
      IER=0
```

```
C
C     TEST FOR MAX FLAT FILTER
C
C
      IF (RIPPLE)10,30,50
C
C     MAX FLAT FILTER
C
   30 GVALUE(1)=1.0
      GVALUE(SECTS+2)=1.0
      DO 40 I=1,SECTS
   40 GVALUE(I+1)=2.*SIN((2*I-1)*PI/(2.*TEMP))
      RETURN
C
C     CHEBYSHEV FILTER
C
   50 TEMP1=2.*TEMP
      TEMP2=RIPPLE/17.37
      TEMP2=COSHF(TEMP2)/SINHF(TEMP2)
      TEMP2=ALOG(TEMP2)/2.
      TEMP3=SINHF(TEMP2/TEMP)
      GVALUE(1)=1.
      GVALUE(2)=4.*SIN(PI/TEMP1)/TEMP3
      TEMP3=TEMP3*TEMP3/4.
      DO 60 I=3,N
      TEMP4=4.*SIN(FLOAT(2*I-5)*PI/TEMP1)*SIN(FLOAT(2*I-3)*PI/TEMP1)
      TEMP4=TEMP4/((TEMP3+SIN(FLOAT(I-2)*PI/TEMP)**2)*GVALUE(I-1))
   60 GVALUE(I)=TEMP4
      IF ( MOD(SECTS,2) )80,70,80
   70 TEMP4=COSHF(TEMP2/2.)/SINHF(TEMP2/2.)
      GVALUE(N+1)=TEMP4*TEMP4
      RETURN
   80 GVALUE(N+1)=1.
      RETURN
      END
      SUBROUTINE MSTRIP(Z,K,HEIGHT,WIDTH,KEFF,IER)
C
C     SUBPROGRAM NO S259 SINGLE MICROSTRIP SYNTHESIS
C
C     SUBROUTINE CALCULATES THE WIDTH,W,AND EFFECTIVE DIELECTRIC CONS-
C     ANT,KEFF,OF A MICROSTRIP LINE GIVEN THE IMPEDANCE OF THE LINE,Z,
C     HEIGHT ABOVE THE GROUNDPLANE,H,(DIELECTRIC THICKNESS) AND THE
C     DIELECTRIC CONSTANT,K. ERROR CODE:0=NO ERROR,1=ERROR IN INPUT
C     DIMENSIONS (0 OR NEGATIVE),2= SOLUTION NOT FOUND IN 10 ITERATIONS
      REAL ZZ(2),KK(2),KEFF,K1,R,K
      IF (HEIGHT)10,20,20
   10 IER=1
      RETURN
   20 IF(K-1.0)10,30,30
   30 IF(Z-5.3/SQRT(K))10,40,40
   40 IER=0
      PI=3.141592653
      A9=0.001
      H=HEIGHT
      N=0
      H1=PI/376.7*Z*SQRT(K+K+2.)
      H1=H1+(K-1.)/(K+1.)*(.2258+.1208/K)
      H2=EXP(H1)
      W=1./(H2/8.-.25/H2)
      Z1=59.96*ALOG(4./W+SQRT(16./W/W+2.))
      KEFF=(Z1/Z)**2
      IF(W)70,70,50
   50 IF(W-1.3)60,70,70
   60 WIDTH=W*H
      RETURN
   70 A=83./Z/SQRT(K)
```

Table 6 concl'd

```
      A=2.5*(A**.4)
   80 DO 90 I=1,2
      A=A+A9
      X=EXP(A)
      D=1.+(X+1./X)/2.
      R1=PI*188.35/D
      S1=.179*(X+1./X)+.953
      S1=.732*(A-ALOG(S1+SQRT(S1*S1-1.)))
      S2=.3836-1./X
      S=S2+(S1-S2)/K
      KK(I)=K-(K-1.)*(A-S)/D
   90 ZZ(I)=R1/SQRT(KK(I))
      Z8=ZZ(1)/2.+ZZ(2)/2.
      IF(ABS(Z8-Z)-.001*Z)130,130,100
  100 N=N+1
      IF(N-10)120,120,110
  110 IER=2
      GO TO 130
  120 A=A-A9*2+A9/(ZZ(2)-ZZ(1))*(Z-Z8)
      GO TO 80
  130 WIDTH=1/PI*(X-1./X-2.*A+A9)*H
      KEFF=KK(1)/2.+KK(2)/2.
      RETURN
      END
      FINISH
```

Table 7

Computer Table 7 Listing of computer program STUB

```
NEW STUB
1 DIM A(26),B(26),G(26),J(26),K(26),Z(26),M(26)
2 PRINT"BANDPASS FILTERS: QUARTERWAVE STUBS & CONNECTING LINES"
6 PRINT"ENTER NOS OF SECTIONS,Z(OHMS) AND FRACTIONAL BANDWIDTH"
7 INPUT N,Z,W
8 Z(0)=Z
9 E=2.7183
10 P1=3.1416
12 G(0)=1
14 PRINT"ENTER 1 FOR TCHEBYSCHEFF; 0 FOR BUTTERWORTH"
15 INPUT T1
16 IF T1=1 THEN 19
17 GOSUB 1300
18 GOTO 20
19 GOSUB 1000
20 FOR K=0 TO (N+1)
21 PRINT"G(";K;")=";G(K)
22 NEXT K
23 PRINT
41 PRINT"SOURCE AND LOAD IMPEDANCE=";Z;"OHMS"
42 PRINT
500 T2=(P1/2)*(1-W/2)
510 C1=2*G(1)
520 J(1)=SQR(C1/G(2))
530 K(1)=Z(0)/J(1)
540 C2=((C1*SIN(T2))/(2*COS(T2)))↑2
550 M(1)=SQR((J(1)↑2)+C2)
560 Z(1)=Z(0)/(M(1)-J(1))
565 IF N=2 THEN 655
570 J(N-1)=SQR((C1*G(N+1))/G(N-1))
575 IF N=3 THEN 630
580 FOR K=2 TO (N-2)
590 J(K)=C1/SQR(G(K)*G(K+1))
600 K(K)=Z(0)/J(K)
610 M(K)=SQR((J(K)↑2)+C2)
620 Z(K)=Z(0)/(M(K-1)+M(K)-J(K-1)-J(K))
625 NEXT K
630 K(N-1)=Z(0)/J(N-1)
640 M(N-1)=SQR((J(N-1)↑2)+C2)
650 Z(N-1)=Z(0)/(M(N-2)+M(N-1)-J(N-2)-J(N-1))
655 Z(N)=Z(1)
660 FOR K=1 TO (N-1)
670 PRINT"K(";K;")=";K(K)
680 NEXT K
690 FOR K=1 TO N
```

Table 7 cont'd

```
700 PRINT"Z(";K;")=";Z(K)
710 NEXT K
720 PRINT"K(1),K(2) .....Z(0) OF CONNECTING LINES(OHMS)"
730 PRINT"Z(1),Z(2)......Z(0) OF STUBS(OHMS)"
740 PRINT"IS ANOTHER DESIGN REQD?ENTER 1 FOR YES,0 FOR NO"
750 INPUT T3
760 IF T3=1 THEN 6
770 GOTO 9999
1000 PRINT"ENTER RIPPLE VALUE(DB)"
1005 INPUT R
1007 PRINT"TCHEBYSCHEFF ELEMENTAL VALUES"
1010 K1=R/17.37
1015 M=LOG((E↑K1+E↑(-K1))/(E↑K1-E↑(-K1)))
1020 Y=M/(2*N)
1021 V=M/4
1025 Q=(E↑Y-E↑(-Y))/2
1030 FOR K=1TON
1035 A(K)=SIN(((2*K-1)*P1)/(2*N))
1040 B(K)=(Q↑2)+((SIN((K*P1)/N))↑2)
1045 NEXT K
1050 G(1)=2*A(1)/Q
1055 FOR K=2TON
1060 G(K)=(4*A(K-1)*A(K))/(B(K-1)*G(K-1))
1065 NEXT K
1066 IF((N/2)-INT(N/2))>0.4 THEN 1069
1067 G(N+1)=((E↑V+E↑(-V))/(E↑V-E↑(-V)))↑2
1068 GOTO 1070
1069 G(N+1)=1
1070 RETURN
1300 PRINT"BUTTERWORTH ELEMENTAL VALUES"
1301 G(N+1)=1
1305 FOR K=1TON
1310 G(K)=2*SIN(((2*K-1)*P1)/(2*N))
1315 NEXT K
1320 RETURN
9999 END
```

Example of the use of computer program MICR (see section 2.1)

A table is required giving Z_0 and velocity ratio for given microstrip linewidths. The substrate material is to be alumina with an effective dielectric constant of 9.6 and thickness 0.635 mm. Results are required for linewidths of 0.05 mm to 1.5 mm with 0.05 mm increments.

```
DO PART 1
(PROG: MICR)


ENTER DIELECTRIC CONSTANT
← 9.6
ENTER SUBSTRATE THICKNESS(MM)
← 0.635
ENTER LOWEST(L),INCREMENT(I) & HIGHEST(H) VALUES OF WIDTH(MM)
L =
← 0.05
I =
← 0.05
H =
← 1.5
```

W(MM)	W(THOU)	Z0(OHMS)	L(G)/L(0)
.050	1.969	115.926	.4158
.100	3.937	97.714	.4122
.150	5.906	86.989	.4102
.200	7.874	79.337	.4087
.250	9.843	73.395	.4076
.300	11.811	68.552	.4067
.350	13.780	64.480	.4059
.400	15.748	60.980	.4045
.450	17.717	57.921	.4020
.500	19.685	55.214	.3997
.550	21.654	52.793	.3977
.600	23.622	50.610	.3959
.650	25.591	48.628	.3942
.700	27.559	46.816	.3927
.750	29.528	45.152	.3913
.800	31.496	43.617	.3899
.850	33.465	42.195	.3887
.900	35.433	40.873	.3875
.950	37.402	39.639	.3864
1.000	39.370	38.485	.3853
1.050	41.339	37.403	.3843
1.100	43.307	36.385	.3833
1.150	45.276	35.426	.3824
1.200	47.244	34.521	.3816
1.250	49.213	33.664	.3807
1.300	51.181	32.851	.3799
1.350	53.150	32.080	.3792
1.400	55.118	31.347	.3784
1.450	57.087	30.649	.3777
1.500	59.055	29.983	.3770

Appendix B

Example of the use of computer program STR2 (see section 2.2)

A table is required giving Z_0 for a range of stripline inner conductor widths. The stripline is to be made on Rexolite 1422 printed circuit board. The dielectric constant of the board is 2.53 and the thickness of a single board is 1.5875 mm, thus the ground plane separation for stripline is 3.175 mm. The copper conductor layer is 0.03556 mm thick, and values of Z_0 are required for linewidths of between 0.2 mm and 2.5 mm with increments of 0.1 mm.

```
  DO PART 1
(PROG: STR2)
ENTER DIELECTRIC CONSTANT
- 2.53
ENTER CONDUCTOR THICKNESS(MM)
- 0.03556
ENTER GROUND PLANE SEPARATION(MM)
- 3.175
ENTER LOWEST(L),INCREMENT(I),HIGHEST(H) VALUES OF WIDTH(MM)
L =
- 0.2
I =
- 0.1
H =
- 2.5


VELOCITY RATIO= .629
```

W(MM)	W(THOU)	W/(B-T)	Z(OHMS)
.200	7.874	.064	129.721
.300	11.811	.096	116.948
.400	15.748	.127	107.530
.500	19.685	.159	100.048
.600	23.622	.191	93.834
.700	27.559	.223	88.515
.800	31.496	.255	83.865
.900	35.433	.287	79.732
1.000	39.370	.319	76.013
1.100	43.307	.350	72.724
1.200	47.244	.382	69.985
1.300	51.181	.414	67.445
1.400	55.118	.446	65.083
1.500	59.055	.478	62.881
1.600	62.992	.510	60.823
1.700	66.929	.541	58.895
1.800	70.866	.573	57.086
1.900	74.803	.605	55.384
2.000	78.740	.637	53.781
2.100	82.677	.669	52.269
2.200	86.614	.701	50.839
2.300	90.551	.733	49.485
2.400	94.488	.764	48.201
2.500	98.425	.796	46.983

```
-
```

Appendix C

Example of the use of computer program PLOTBP (see section 3.1)

A bandpass filter with a Butterworth maximally flat response is required for use at L-band. The centre frequency is to be 1.55 GHz, and a 3dB bandwidth of 8% (fractional bandwidth 0.08) is required. A rejection of at least 12 dB is essential at 1.4 GHz. The filters are to be made in stripline form on Rexolite 2200 where the approximate unloaded Q of the resonators is 320.

(i) How many sections are required to meet the specification?

(ii) Plot the theoretical frequency-transducer gain response for such a filter between 1 GHz and 2 GHz with 0.05GHz increments in frequency.

(iii) Obtain an estimate of the increase in mid-band loss, due to dissipation, which would be expected for such a filter.

```
RUN
              RUN PROCEEDING
BAND-PASS FILTERS WITH TCHEBYSCHEFF OR BUTTERWORTH RESPONSES
ENTER ALL FREQUENCIES IN HZ
ENTER 1 TO SPECIFY BAND EDGES: 0 FOR
CENTRE FREQ & FRACTIONAL BANDWIDTH
← 0
ENTER CENTRE FREQ & FRACTIONAL BANDWIDTH
← 1.55E9,0.08
F1= .1488E+10          F2= .1612E+10
BANDWIDTH= 8 %         F(0)= .155E+10   HZ
ENTER REQD [illegible] & FREQ WHERE THIS IS REQD
← 12,1.4E9
ENTER 1 FOR TCHEBYSCHEFF [illegible] 0 FOR BUTTER[illegible]
← 0
             TRANSDUCER [illegible]= 15.48   DB AT .14E+10 HZ
IS PLOT [illegible]? ENTER 1 FOR YES: 0 FOR NO
← 1
ENTER NO. OF ELEMENTS,& FRACTIONAL BANDWIDTH
← 2,0.08
Y-AXIS:ENTER MIN,MAX,INC FOR FREQ
← 1E9,2E9,0.05E9
X-AXIS:ENTER MAX ATTENUATION(DB)
← 40
```

```
                         TRANSDUCER GAIN(DB)
                   0        -8        -16       -24       -32       -40
                    !.........!.........!.........!.........!.........!
 FREQ   GAIN

 .2E+10
       34.7376      .                                          +
 .195E+10
       32.6181      .                                       +
 .19E+10
       30.2369      .                                    +
 .185E+10
       27.5095      .                                 +
 .18E+10
       24.3069      .                             +
 .175E+10
       20.4189      .                        +
 .17E+10
       15.4797      .                  +
 .165E+10
       8.89241      .          +
 .16E+10
       1.52501      .+
 .155E+10
       0            +
 .15E+10
       1.52528      .+
 .145E+10
       8.89281      .          +
 .14E+10
       15.48        .                  +
 .135E+10
       20.4191      .                        +
 .13E+10
       24.3071      .                             +
 .125E+10
       27.5096      .                                 +
 .12E+10
       30.237       .                                    +
 .115E+10
       32.6182      .                                       +
 .11E+10
       34.7377      .                                          +
 .105E+10
       36.654       .                                             +
 .1E+10
       38.4094      .                                               +
IS APPROX Q OF RESONATORS KNOWN?
ENTER 1 FOR YES: 0 FOR NO
← 1
ENTER APPROX VALUE OF UNLOADED Q OF RESONATORS
← 320
MIDBAND LOSS INCREASE DUE TO DISSIPATION= .479839 DB APPROX
IS ANOTHER PLOT REQD? ENTER 1 FOR YES: 0 FOR NO
← 0

                FINISHED

←
```

Appendix D

Example of the use of computer program BPLE (see section 3.3)

Design a three-section bandpass filter with a centre frequency of 1 GHz and a bandwidth of 20%. A Tchebyscheff response is required with 0.1dB ripple in the pass-band. The source and load impedances are to be 50 ohm.

```
RUN
                RUN PROCEEDING
LUMPED-ELEMENT BAND-PASS FILTERS
DO NOT USE EVEN NOS OF SECTIONS
FOR TCHEBYSCHEFF RESPONSE
ENTER NOS OF SECTIONS,Z(OHMS),CENTRE FREQ(HZ),
AND FRACTIONAL BANDWIDTH
- 3,50,1E9,0.2
ENTER 1 FOR TCHEBYSCHEFF; 0 FOR BUTTERWORTH
- 1
ENTER RIPPLE VALUE(DB)
- 0.1
TCHEBYSCHEFF ELEMENTAL VALUES
G( 0 )= 1
G( 1 )= 1.03158
G( 2 )= 1.1474
G( 3 )= 1.03157
G( 4 )= 1

SOURCE AND LOAD IMPEDANCE= 50    OHMS
C( 1 )= .164181E-10    F       L( 1 )= .154282E-8 H
C( 2 )= .554836E-12    F       L( 2 )= .456534E-7 H
C( 3 )= .164179E-10    F       L( 3 )= .154284E-8 H
C(1)L(1);C(3)L(3)....PARALLEL TUNED
C(2)L(2);C(4)L(4)....SERIES TUNED


FOR DUAL
C( 1 )= .617129E-12    F       L( 1 )= .410452E-7 H
C( 2 )= .182614E-10    F       L( 2 )= .138709E-8 H
C( 3 )= .617135E-12    F       L( 3 )= .410448E-7 H
C(1)L(1);C(3)L(3)....SERIES TUNED
C(2)L(2);C(4)L(4)....PARALLEL TUNED
IS ANOTHER DESIGN REQD?
ENTER 1 FOR YES; 0 FOR NO
- 0

                    FINISHED
-
```

Appendix E

Example of the use of computer program BECFI (see section 3.4)

A five-section bandpass filter is required with a centre frequency of 0.85 GHz and a 23.5% bandwidth. A Tchebyscheff response with 0.5dB ripple is required. Find the even- and odd-mode impedances if the source and load impedances are 50 ohm.

The layout of the filter is shown in Fig.7a.

```
    - RUN
           RUN PROCEEDING
EDGE-COUPLED BAND-PASS FILTERS
ENTER NOS OF SECTIONS,Z(OHMS) AND FRACTIONAL BANDWIDTH
- 5,50,0.235
ENTER 1 FOR TCHEBYSCHEFF; 0 FOR BUTTERWORTH
- 1
ENTER RIPPLE VALUE(DB)
- 0.5
TCHEBYSCHEFF ELEMENTAL VALUES
G( 0 )= 1
G( 1 )= 1.70582
G( 2 )= 1.22961
G( 3 )= 2.54088
G( 4 )= 1.22961
G( 5 )= 1.7058
G( 6 )= 1

SOURCE AND LOAD IMPEDANCE= 50   OHMS

ZOE(OHMS)     ZOO(OHMS)        C            CF(DB)
 84.0794       37.5606      .38243        -8.34898       S( 0 , 1 )
 65.9923       40.5041      .239333       -12.42         S( 1 , 2 )
 62.6227       41.7387      .200112       -13.9746       S( 2 , 3 )
 62.6227       41.7387      .200112       -13.9746       S( 3 , 4 )
 65.9924       40.5041      .239335       -12.4199       S( 4 , 5 )
 84.0796       37.5606      .382431       -8.34895       S( 5 , 6 )
IS ANOTHER DESIGN REQD ? ENTER 1 FOR YES: 0 FOR NO
- 0

               FINISHED
```

Appendix F

Example of the use of computer program BDPS (see section 3.4.1)

In order to use this program the following data is required.

Z_0	The impedance level in ohm.
DIEK	The substrate dielectric constant
H	The substrate thickness in mm
BAND	The filter bandwidth in GHz (if negative a correction factor is applied for bandwidth shrinkage)
CENTER	Filter centre frequency in GHz
RIPPLE	Tchebyscheff ripple value in dB; if zero a Butterworth maximally flat response is assumed
SECTN	The number of sections or zero if it is required that the number of sections be computed from the next data
FREQ	Frequency in GHz outside of the pass-band where a specified rejection is required or zero if SECTN is known
ATTEN	The rejection in dB at FREQ above or zero if SECTN is known

The data is fed into the computer using the NAMELIST format as shown in the example below.

EXAMPLE: A filter is required with a centre frequency of 5.75 GHz and a bandwidth of 575 MHz. A Tchebyscheff response is required with a 0.1dB ripple. At 7.0 GHz a rejection of at least 30 dB is required. The input and output impedances are to be 50 ohms. What are the physical dimensions of such a filter made on alumina of 0.635mm thickness and of dielectric constant 9.6?

Data:–

```
∇&CONST
∇Z0=50.0,DIEK=9.6,H=0.635,BAND=0.575,CENTER=5.75
∇&END
∇&DONST
∇RIPPLE=0.1,SECTN=0.0,FREQ=7.0,ATTEN=30.0
∇&END
```

∇ indicates a space

Computer output:—

PARALLEL COUPLED MICROSTRIP FILTER

```
 5.750 GHZ CENTER FREQUENCY  0.575 GHZ BANDWIDTH
 0.100 DB RIPPLE                   3 SECTIONS
 0.025 INCH SUBSTRATE        9.600 DIELECTRIC CONSTANT
50.0 OHM MICROSTRIP INPUT LINE OF WIDTH  0.0249 INCHES
 0.575 GHZ BANDWIDTH DUE TO PRE-COMPENSATION

 50.0 OHM INPUT LINEWIDTH=  0.6323 MM

SEC ELEMENT    WIDTH     GAP     LENGTH     ZOO     ZOE
NUM  VALUE    INCHES   INCHES    INCHES    OHMS    OHMS

 0   1.0000   0.0177   0.0065    0.202    38.10   77.12
W =   0.4492MM
S =   0.1650MM
L =   5.1345MM


 1   1.0316   0.0238   0.0230    0.197    43.82   58.26
W =   0.6037MM
S =   0.5854MM
L =   5.0025MM


 2   1.1474   0.0238   0.0230    0.197    43.82   58.26
W =   0.6037MM
S =   0.5854MM
L =   5.0025MM


 3   1.0316   0.0177   0.0065    0.202    38.10   77.12
W =   0.4492MM
S =   0.165_MM
L =   5.1345MM
```

The layout of this filter is shown in Fig.7a.

Appendix G

Example of the use of computer program STUB (see section 3.5)

Design a bandpass filter with a Tchebyscheff response and a 0.01dB ripple. The centre frequency is to be 5 GHz with a 50% bandwidth. The source and load impedances are to be 50 ohm.

```
- RUN
              RUN PROCEEDING
BANDPASS FILTERS: QUARTERWAVE STUBS & CONNECTING LINES
ENTER NOS OF SECTIONS,Z(OHMS) AND FRACTIONAL BANDWIDTH
- 5,50,0.5
ENTER 1 FOR TCHEBYSCHEFF; 0 FOR BUTTERWORTH
- 1
ENTER RIPPLE VALUE(DB)
- 0.01
TCHEBYSCHEFF ELEMENTAL VALUES
G( 0 )= 1
G( 1 )= .756304
G( 2 )= 1.30492
G( 3 )= 1.57731
G( 4 )= 1.30492
G( 5 )= .756326
G( 6 )= 1

SOURCE AND LOAD IMPEDANCE= 50   OHMS

X( 1 )= 46.4397
X( 2 )= 47.4214
X( 3 )= 47.4213
X( 4 )= 46.4396
Z( 1 )= 47.9339
Z( 2 )= 23.8406
Z( 3 )= 23.7156
Z( 4 )= 23.8406
Z( 5 )= 47.9339
X(1),X(2) .....Z(0) OF CONNECTING LINES(OHMS)
Z(1),Z(2)......Z(0) OF STUBS(OHMS)
IS ANOTHER DESIGN REQD?ENTER 1 FOR YES,0 FOR NO
- 0

                  FINISHED
-
```

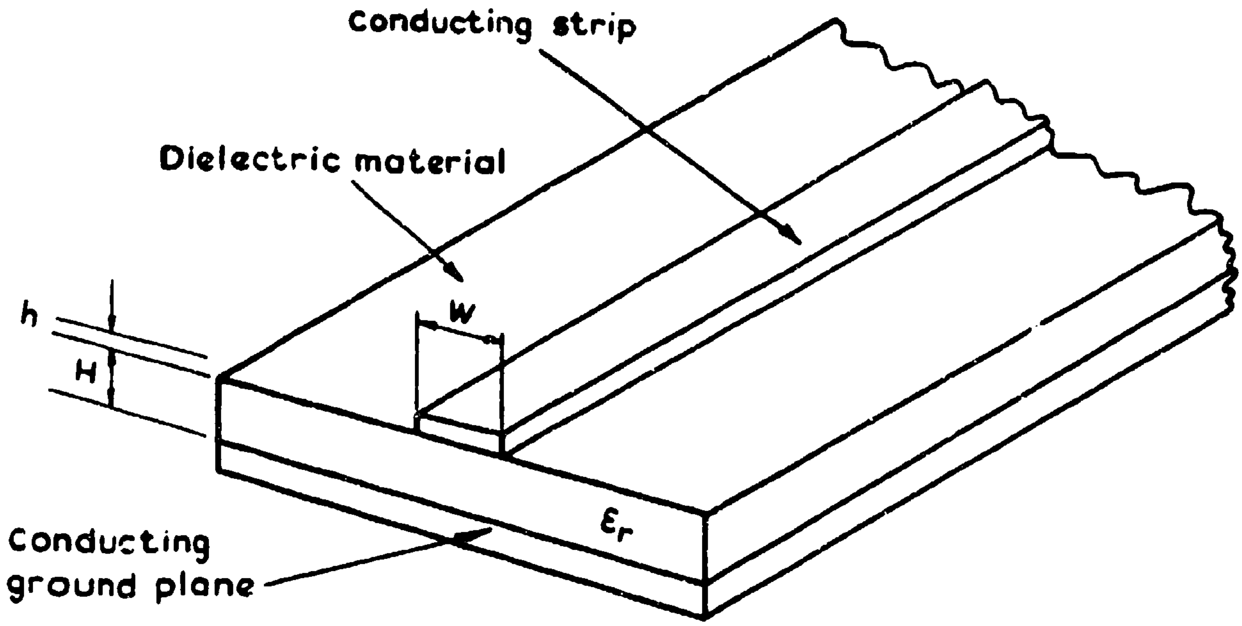


Fig. 1 Microstrip structure

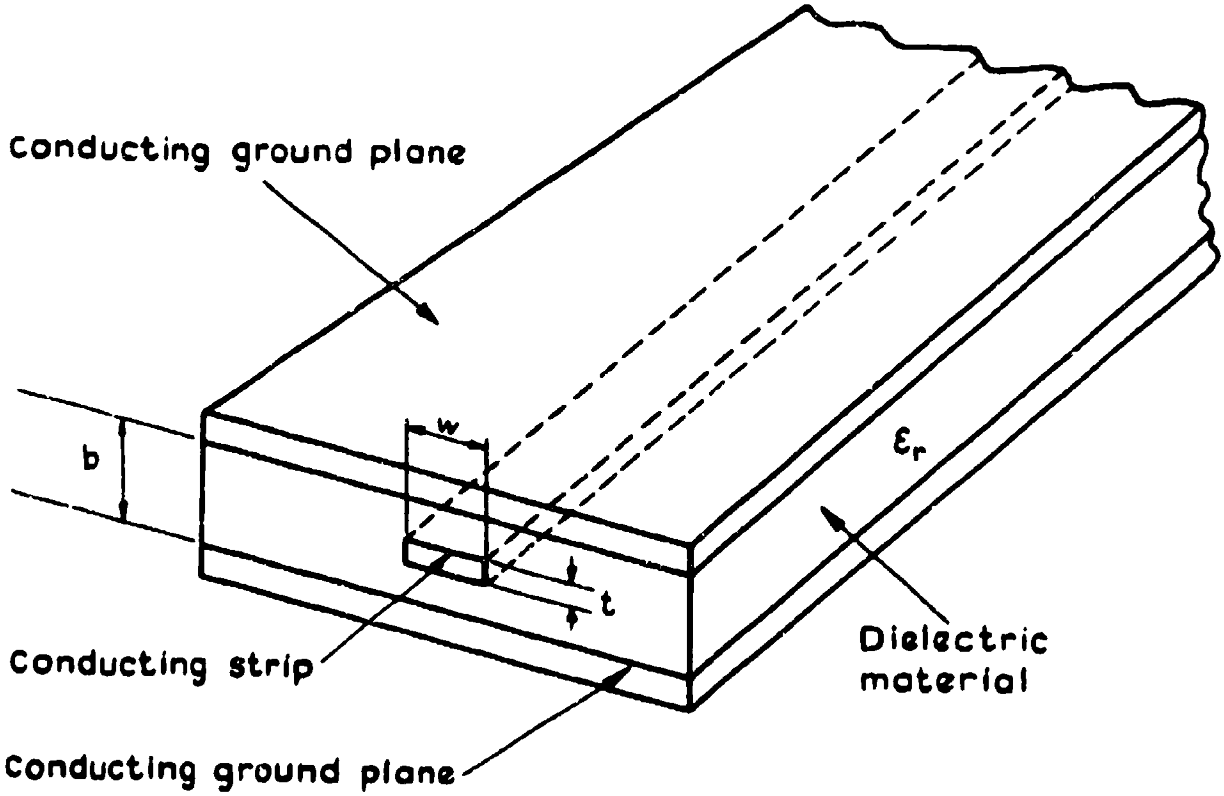
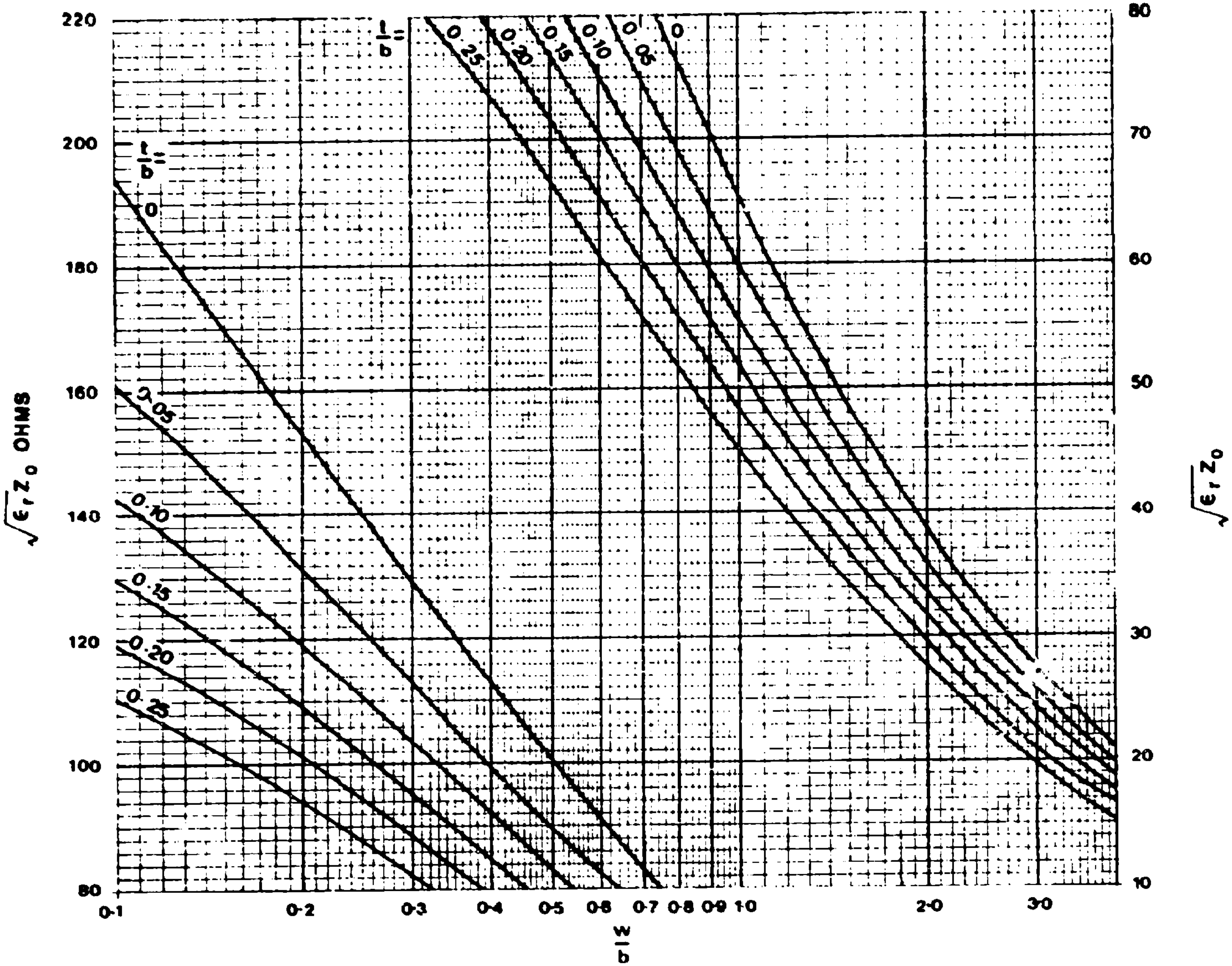


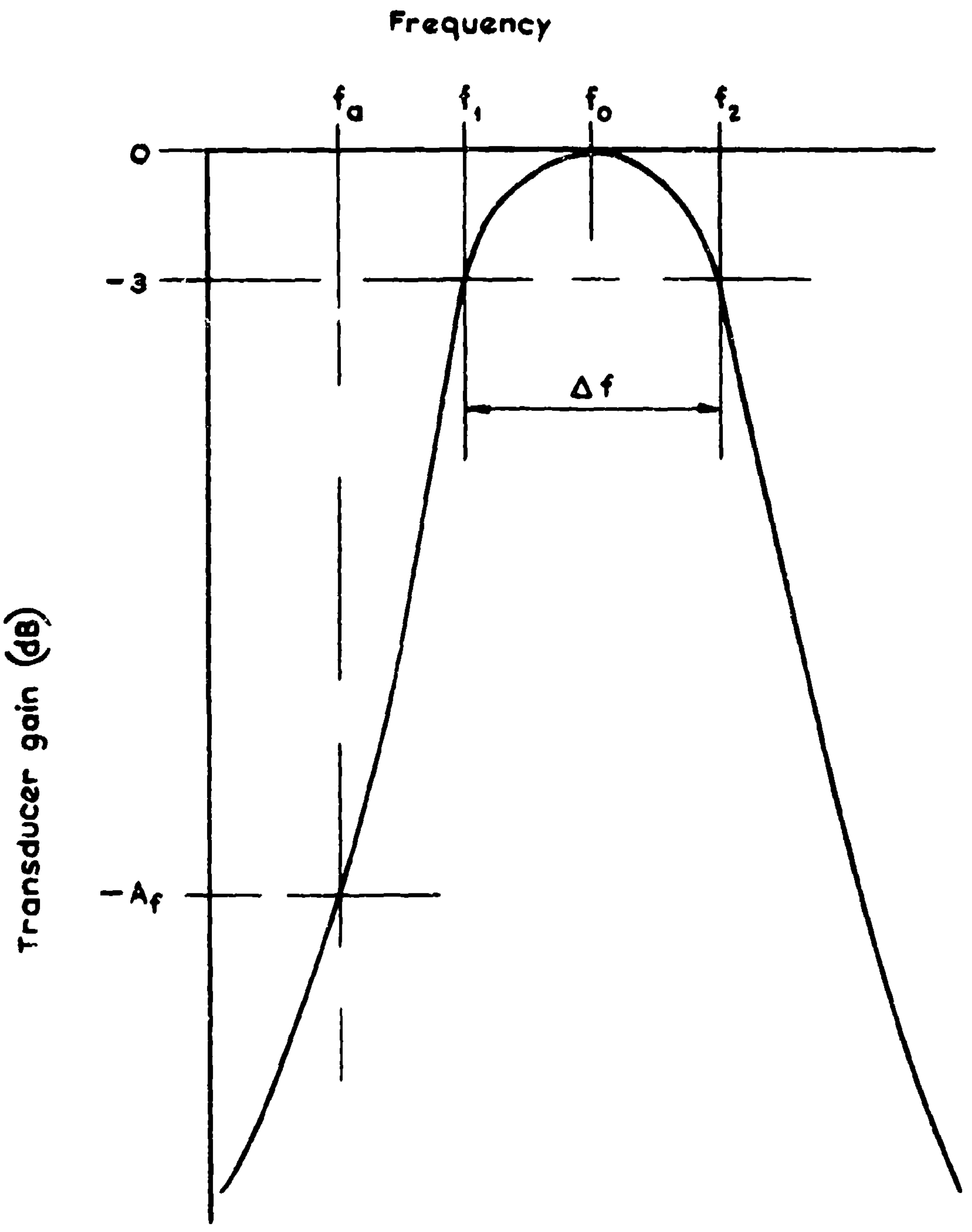
Fig. 2 Stripline structure

Fig. 3



Graph of Z_0 versus w/b for various values of t/b

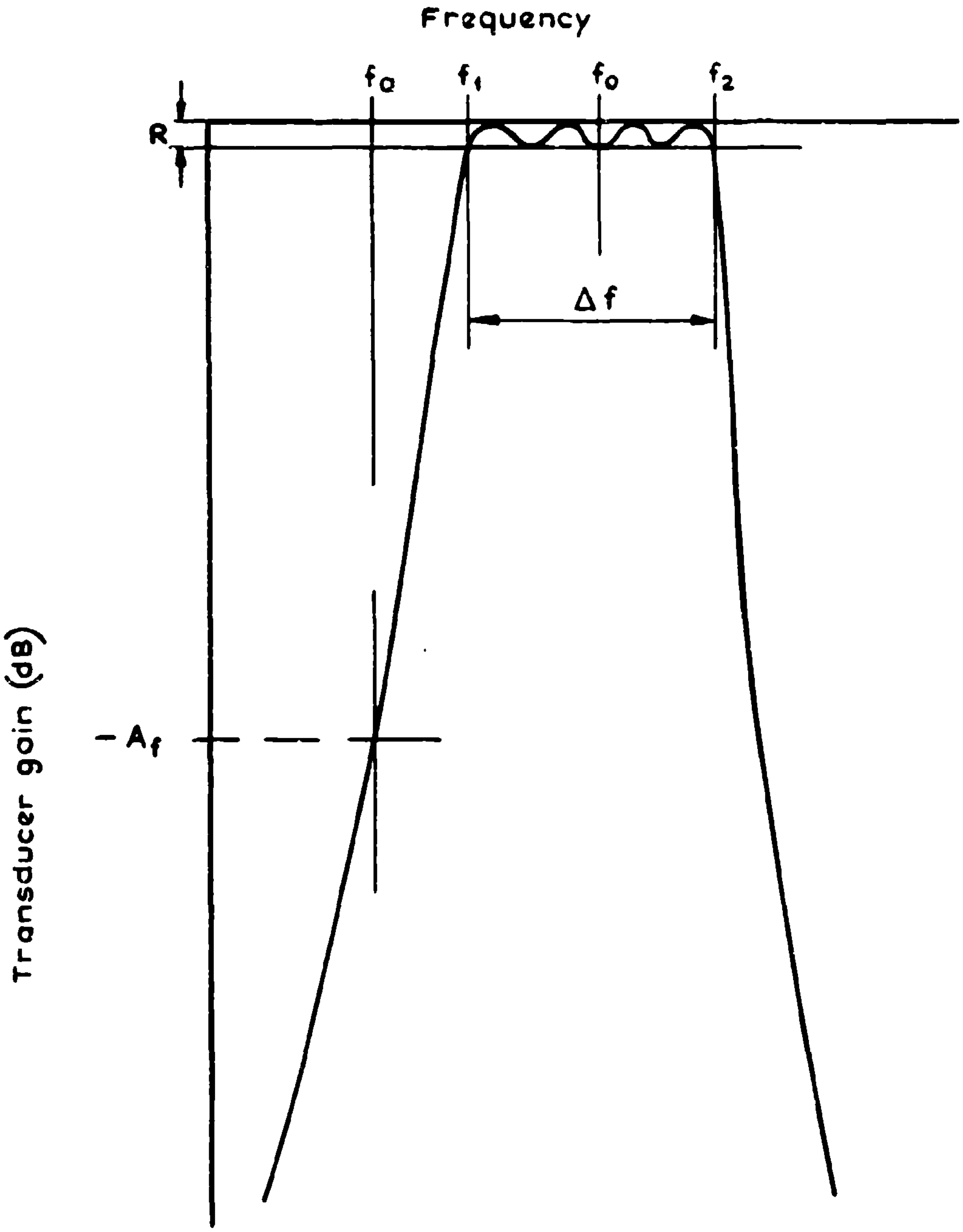
TH 74068 C11185



TR 74068

Fig. 4 Typical Butterworth maximally - flat response

Fig. 5



TR 74068

Fig. 5 Typical Tchebyscheff equal-ripple response

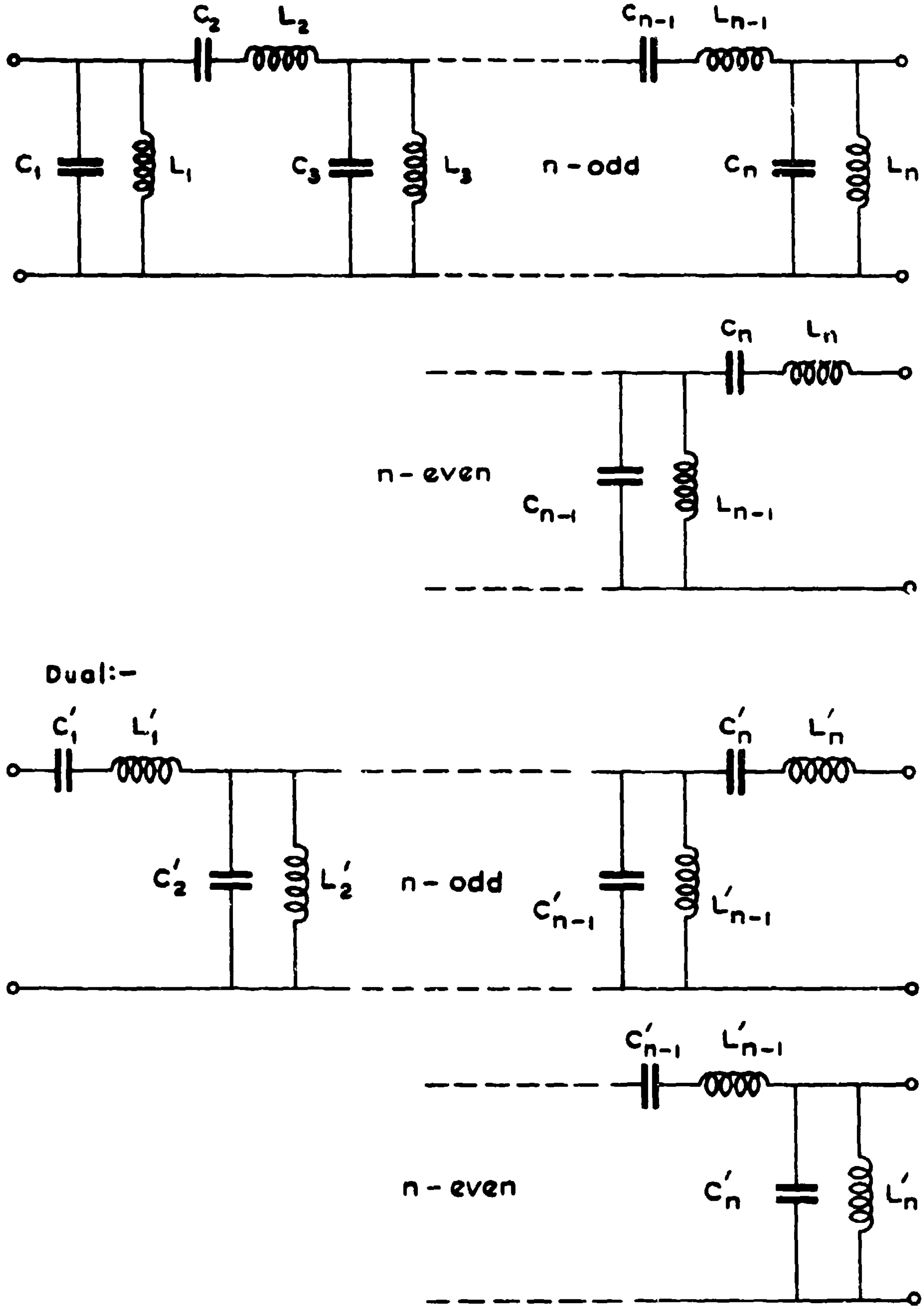
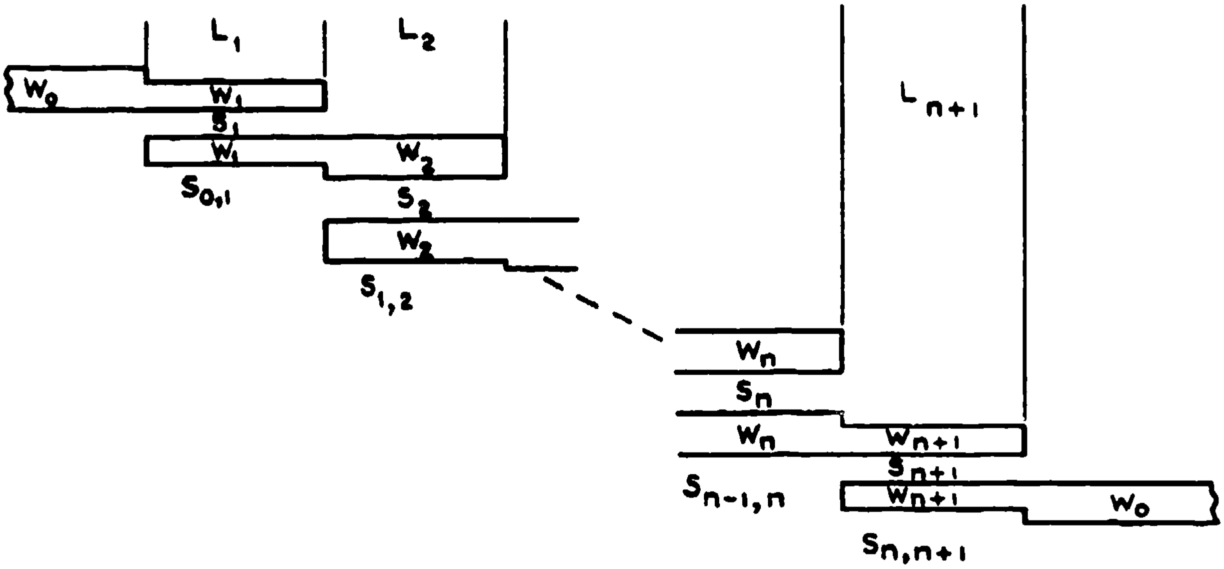


Fig.6 Layout of lumped element filter and its dual

Fig. 7a&b



W_0 width of input and output lines

$S_{0,1}$, $S_{1,2}$ ------ number of coupled section

W_1, W_2, ------ widths of coupled lines

S_1, S_2, ------ gaps between coupled lines

L_1, L_2, ------ lengths of coupled sections

Fig. 7a Layout of parallel-coupled resonator filter

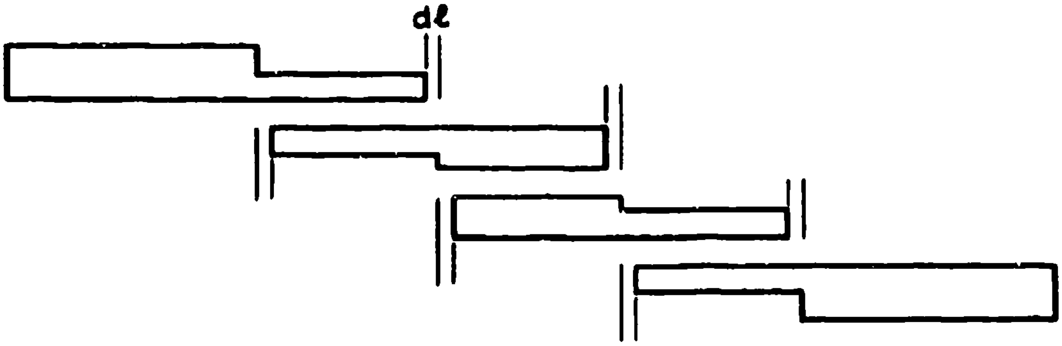


Fig. 7b Application of resonator end corrections

Fig.8

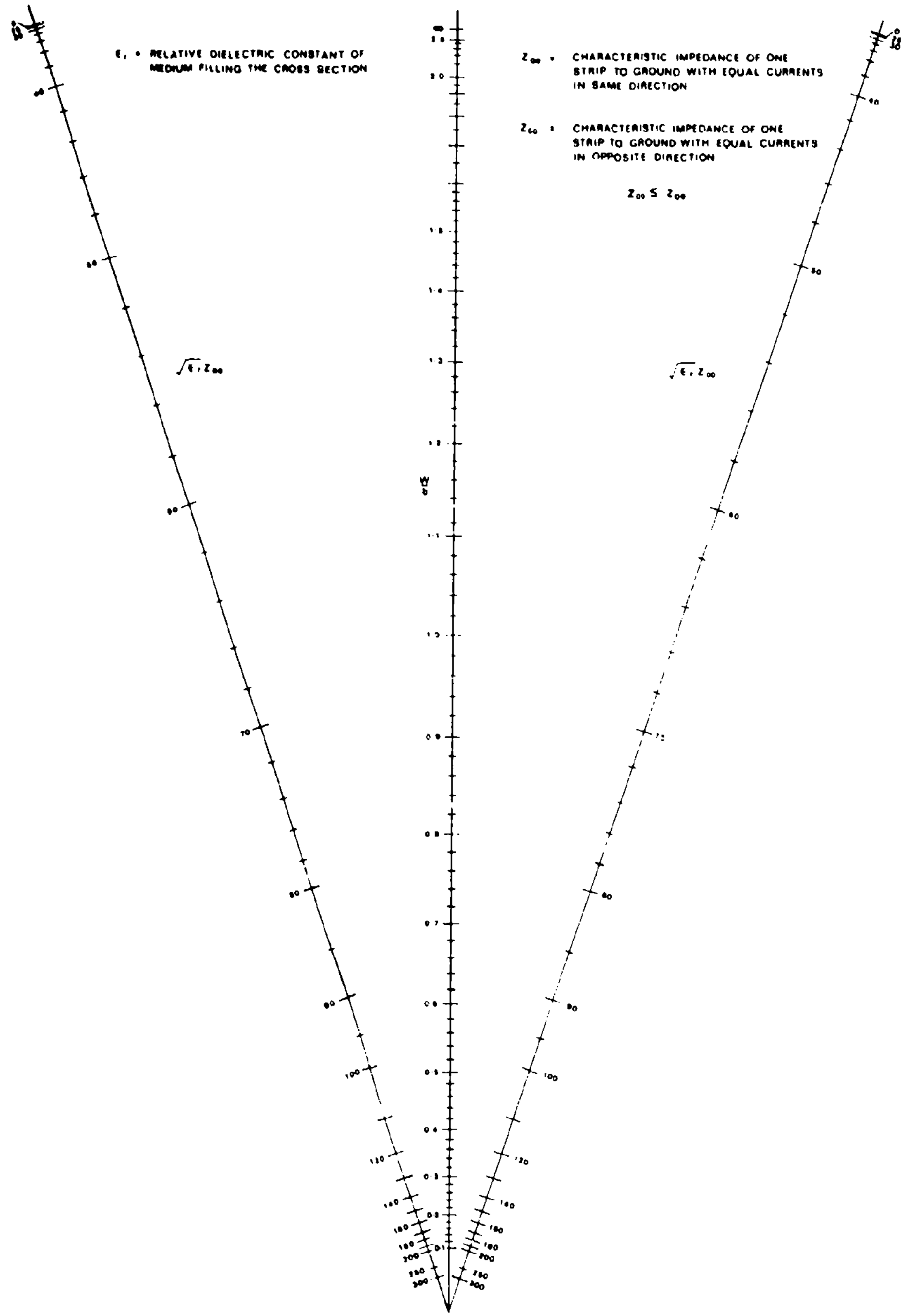


Fig.8 Nomogram giving W/b as a function of Z_{oe} and Z_{oo} in coupled strip line

008 005428

Fig.9

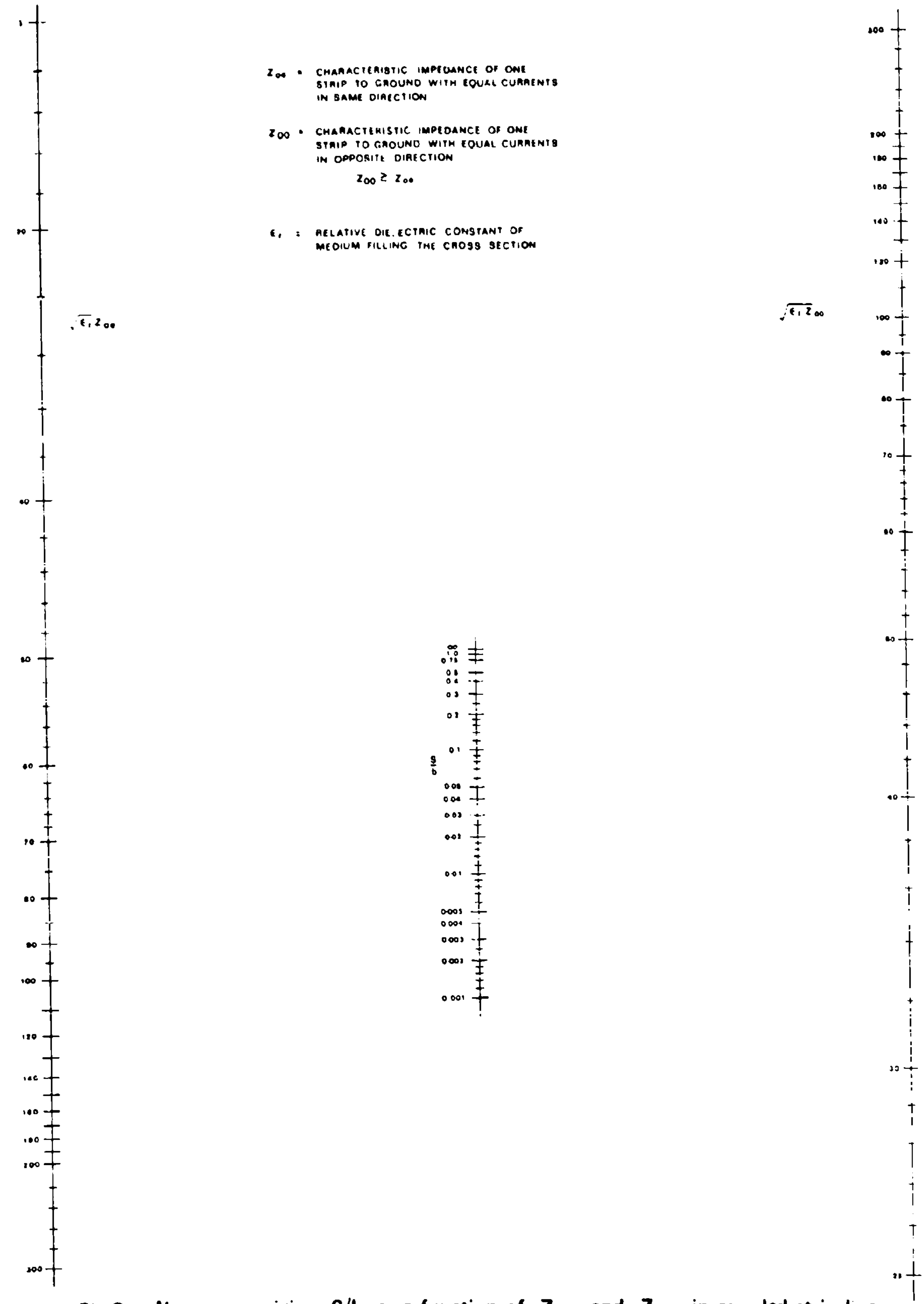
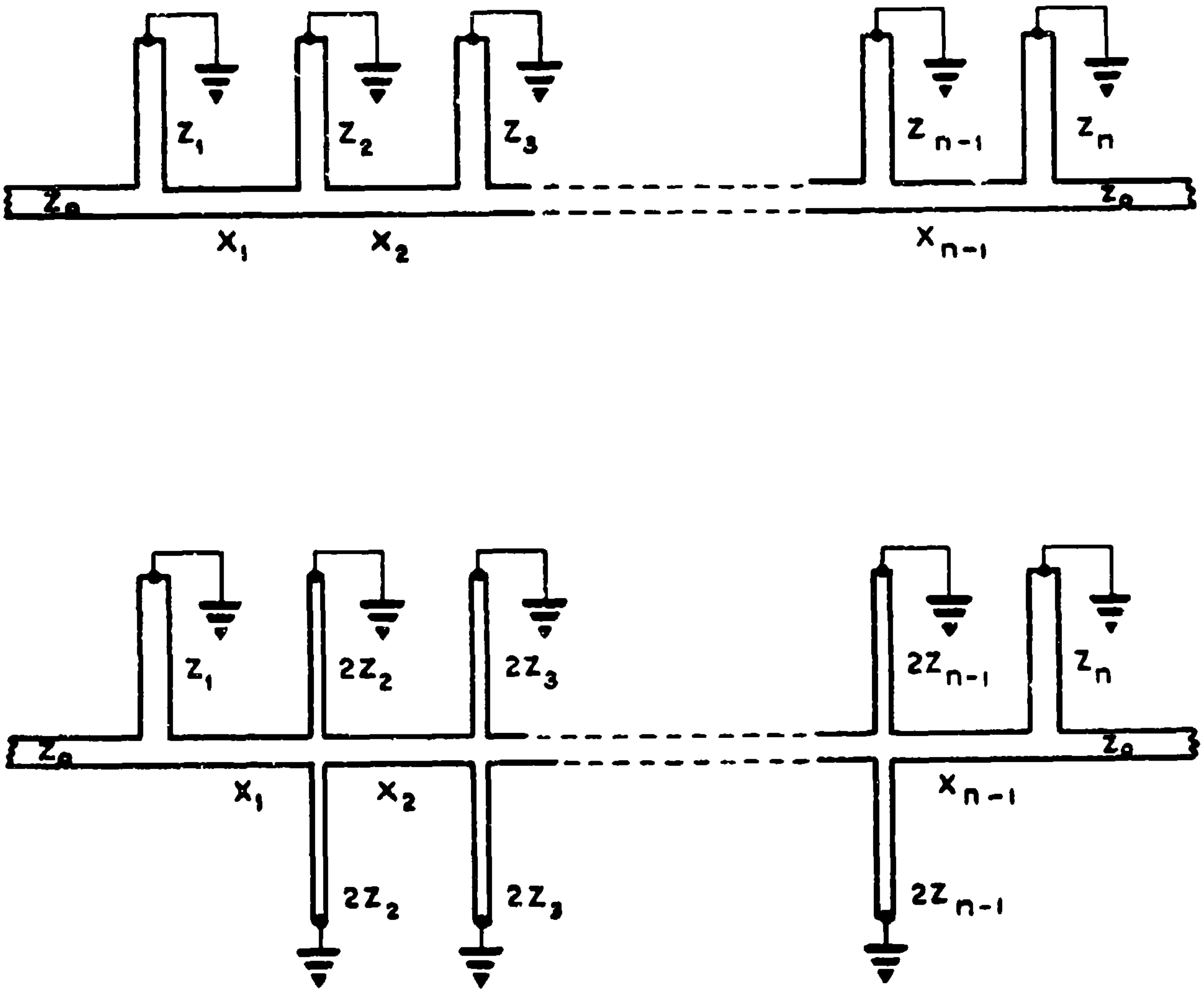


Fig.9 Nomogram giving S/b as a function of Z_{oe} and Z_{oo} in coupled strip line

308 005433



TR 74088

Z_o characteristic impedance of input and output lines

Z_1, Z_2 --- characteristic impedances of stubs

X_1, X_2 --- characteristic impedances of connecting lines

Fig.10 Two possible layouts for stub filter

Fig.11

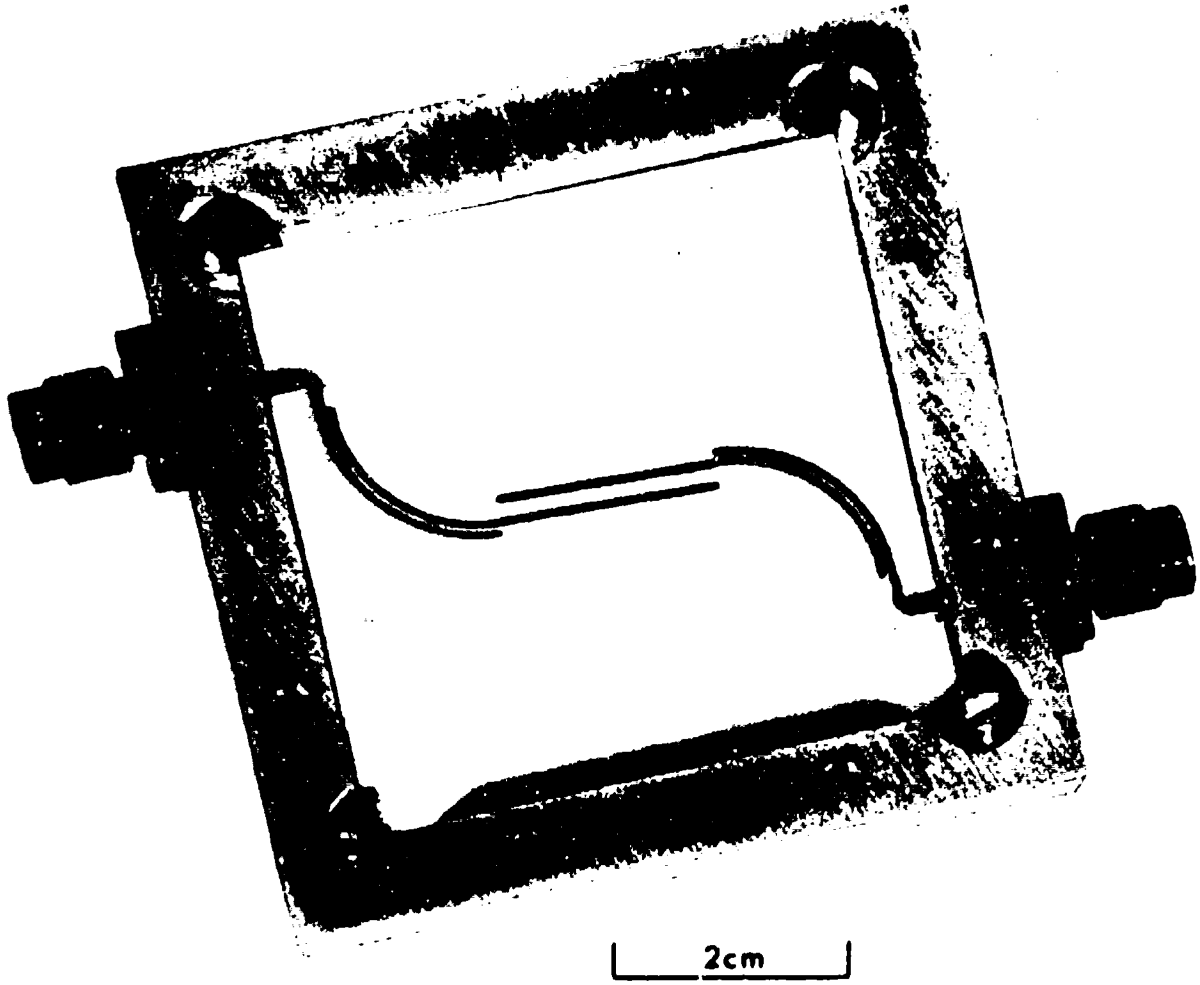


Fig.11 L-band filter A

TR 74068 C11296

Fig.12&13

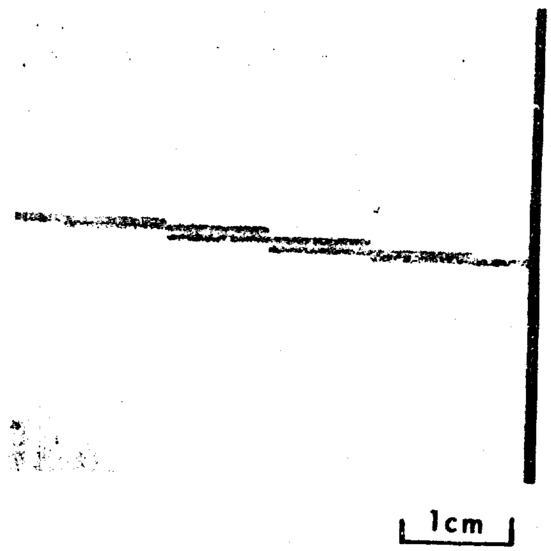


Fig.12 S-band filter B

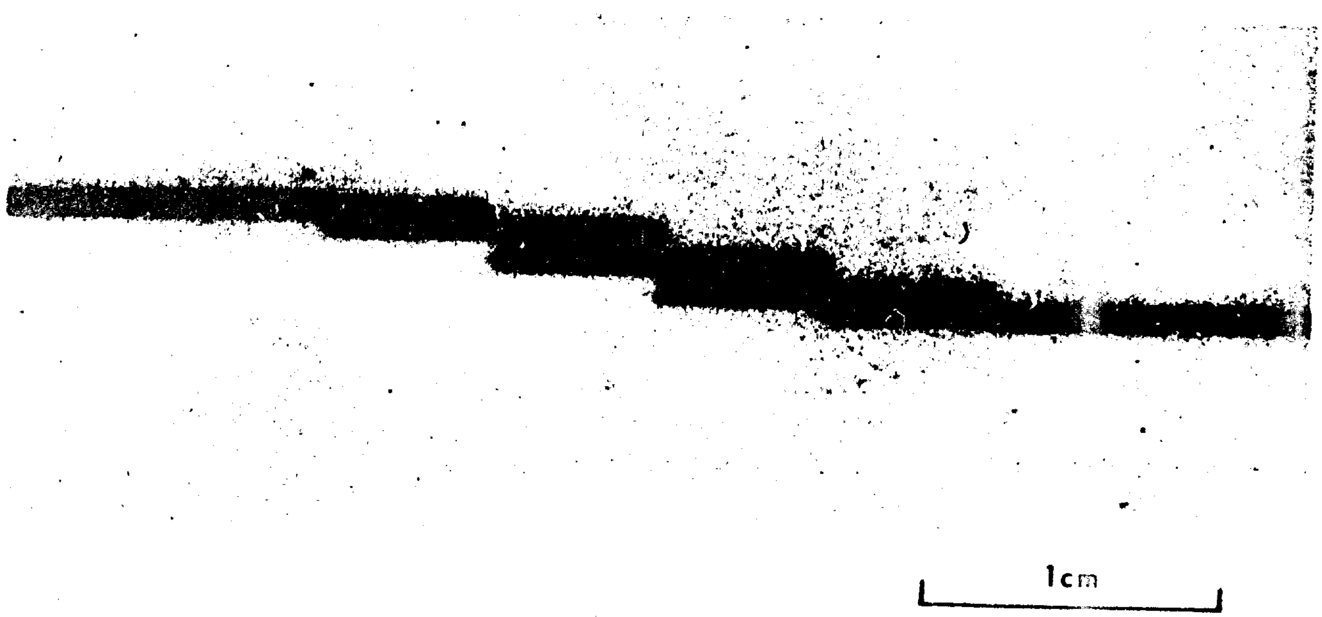


Fig.13 C-band filter C

Fig.14&15

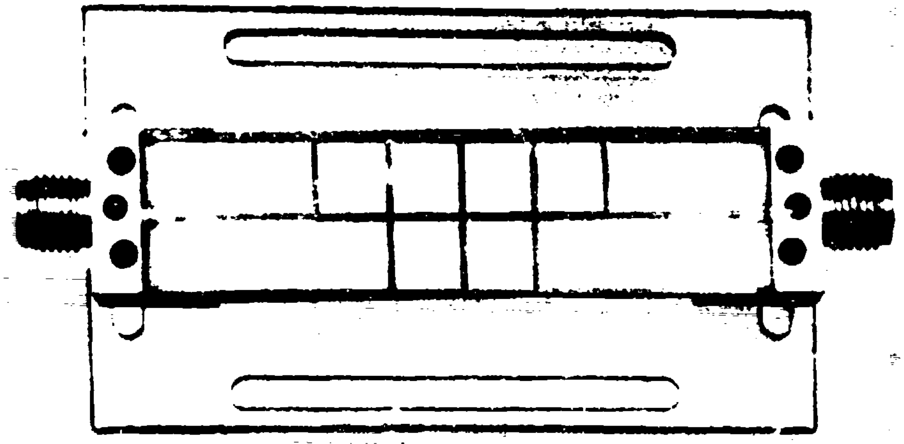


Fig.14 C-band filter D

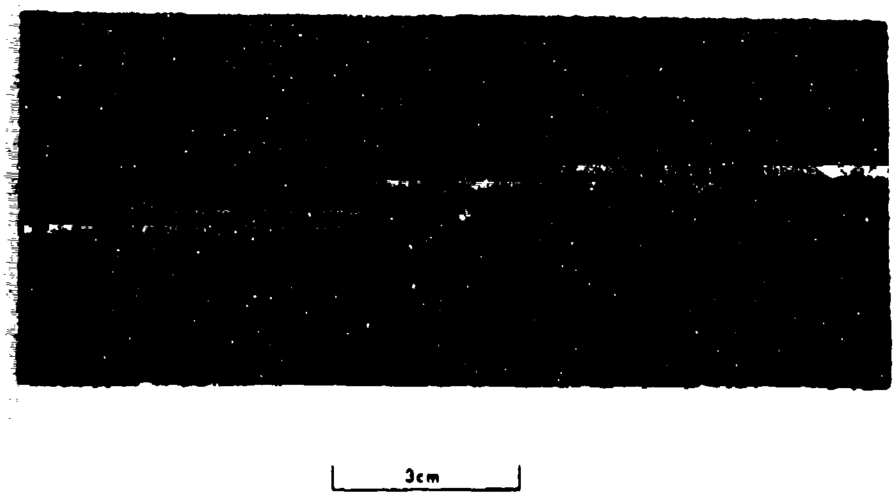


Fig.15 L-band filter E

TR 74068 C11298

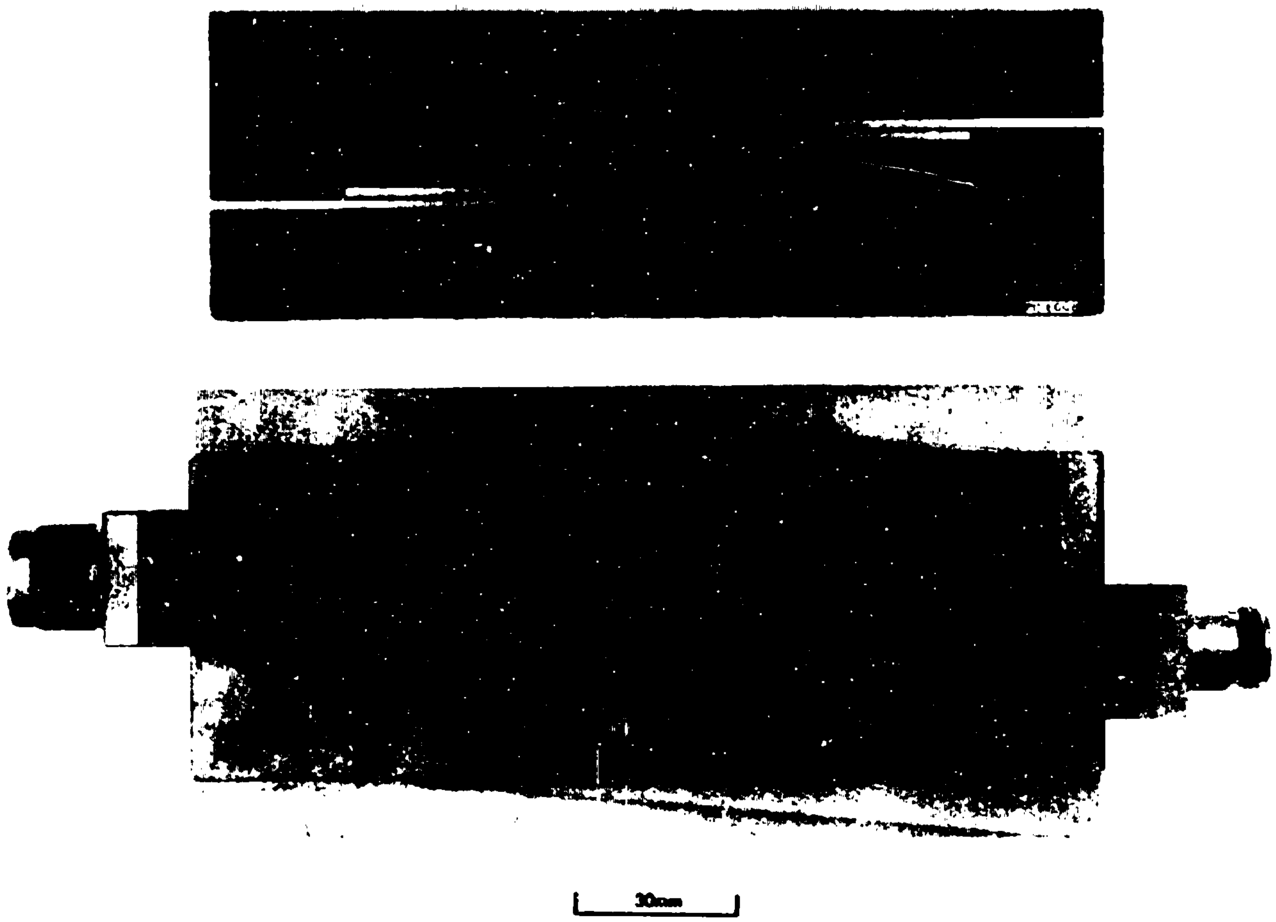


Fig.16 L-band filter F

Fig.17

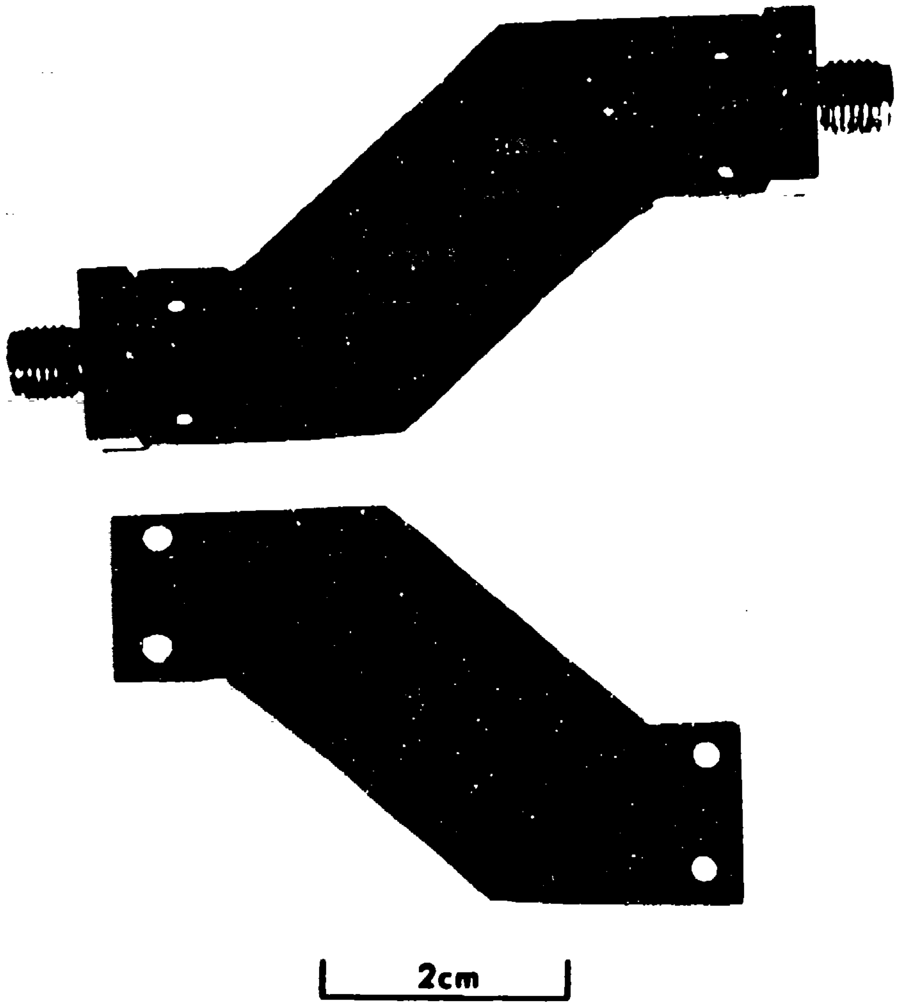


Fig.17 X-band filter G

Fig.18

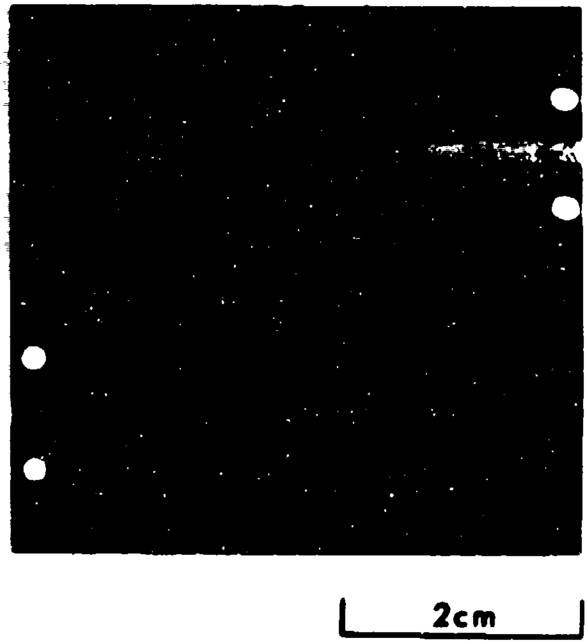


Fig.18 X-band filter H

Fig.19&20

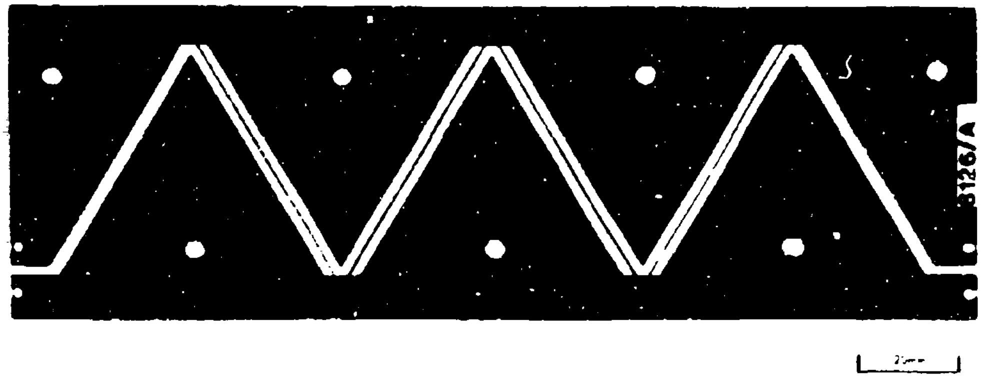


Fig.19 850MHz filter I

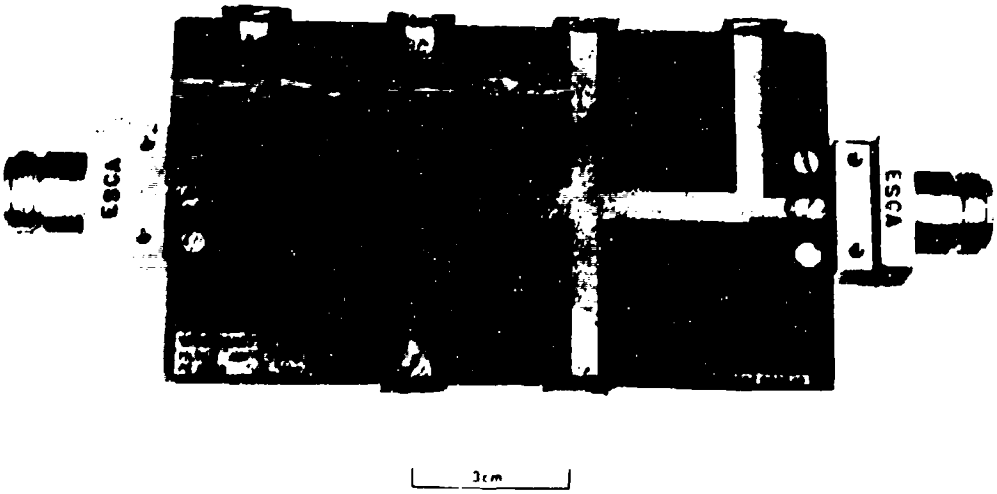


Fig.20 L-band filter J

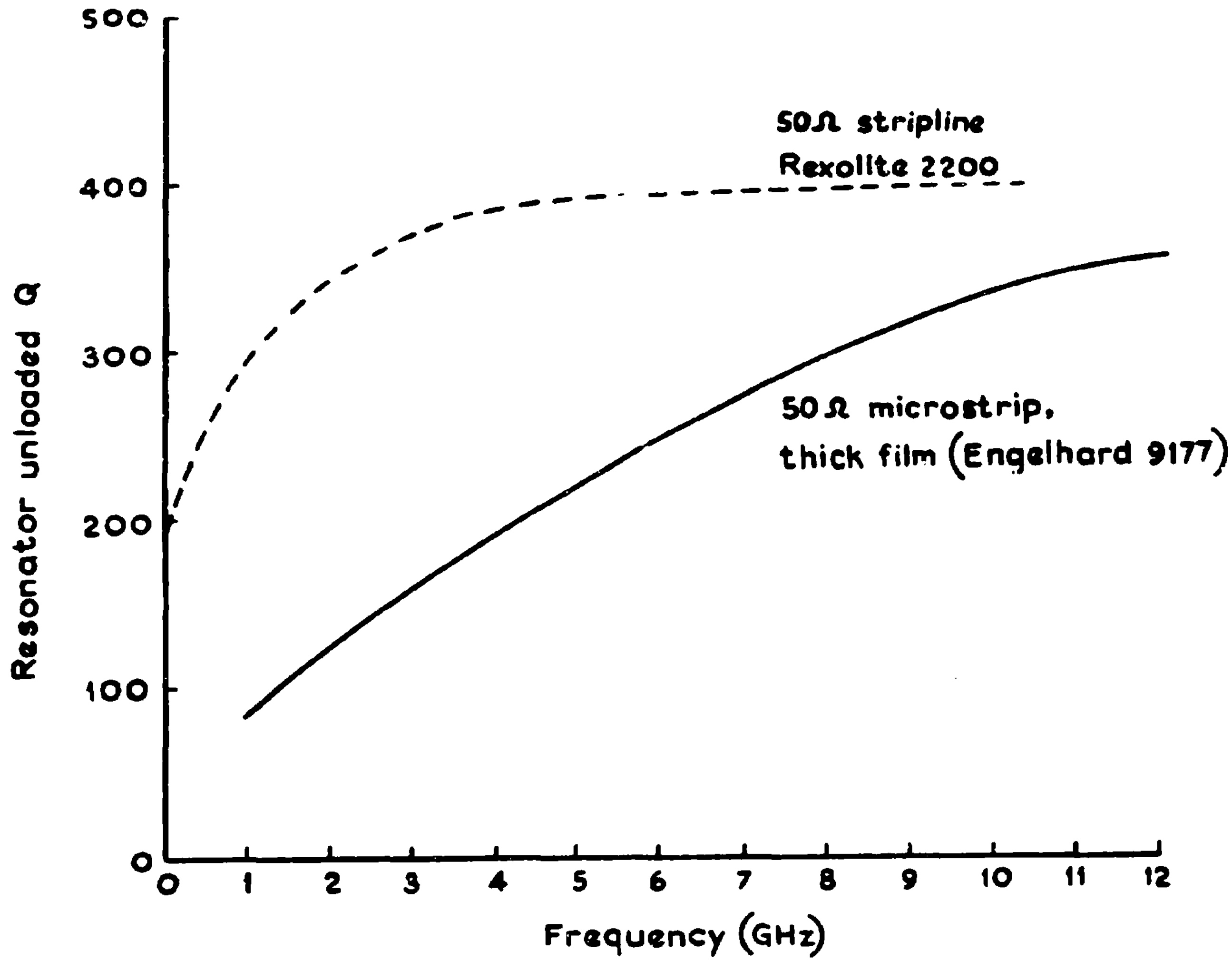


Fig. 21 Variation of unloaded Q with frequency

Fig. 21

61

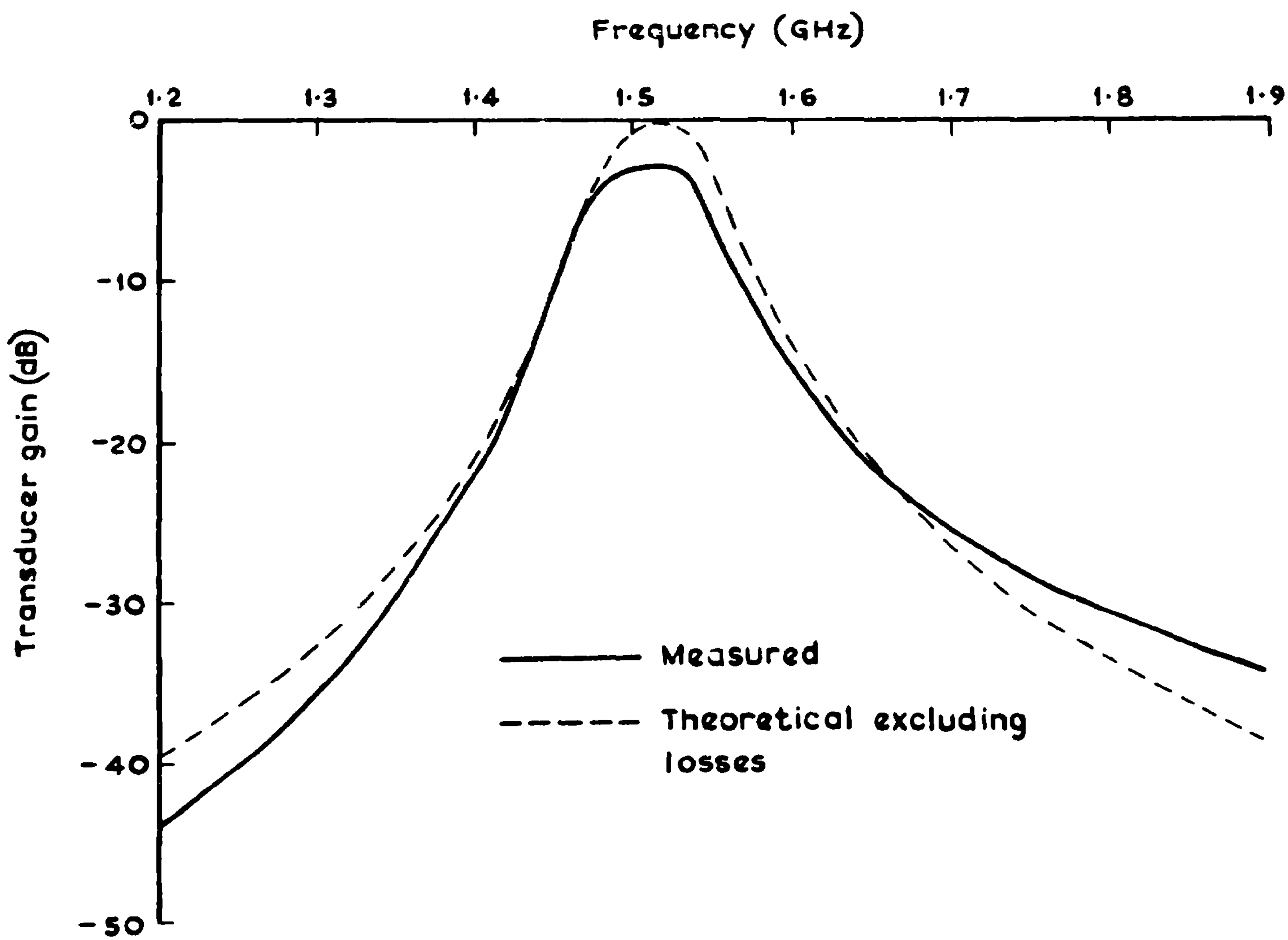


Fig. 22 Frequency response of filter A

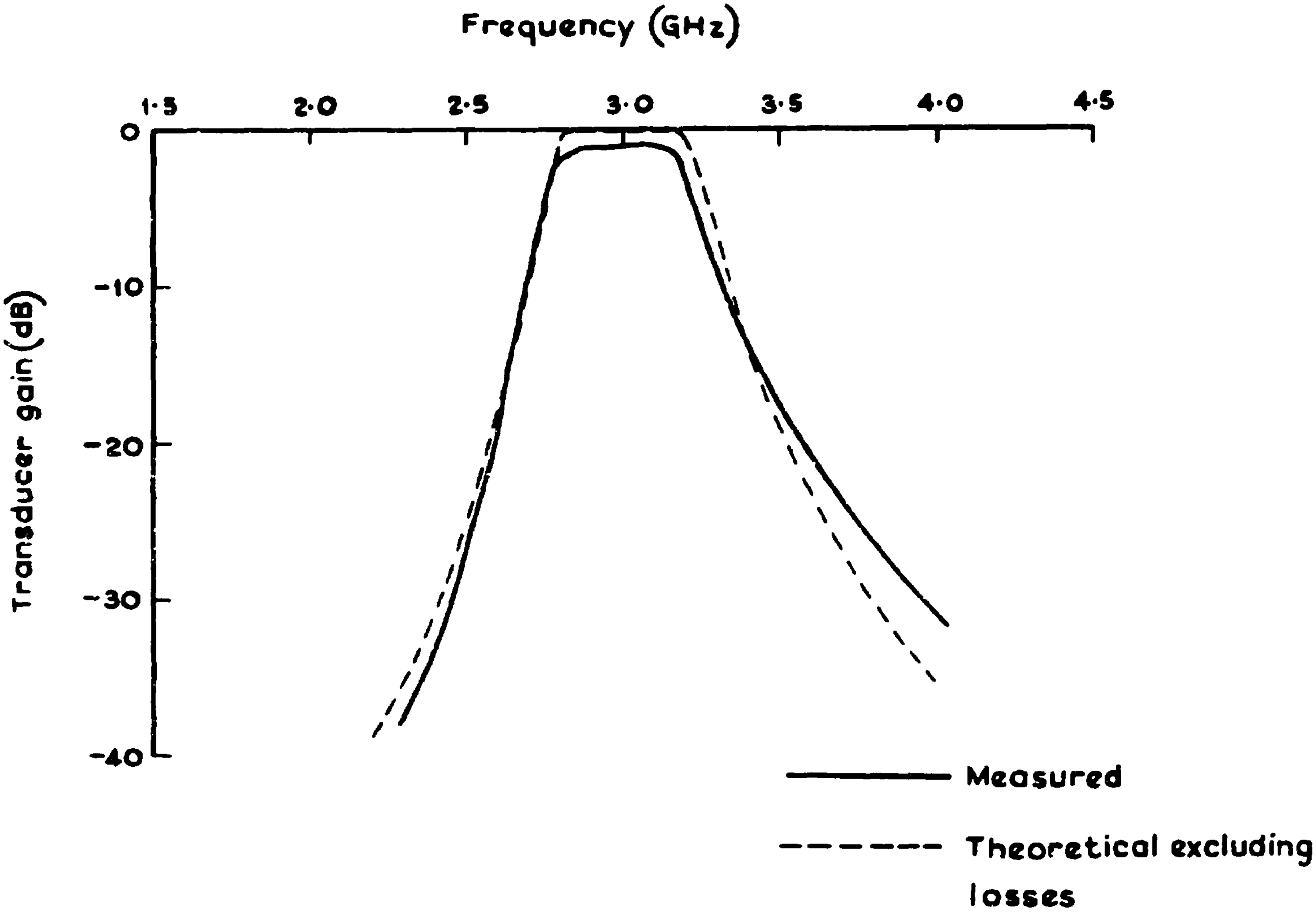


Fig. 23 Frequency response of filter B

Fig.23

Fig. 24

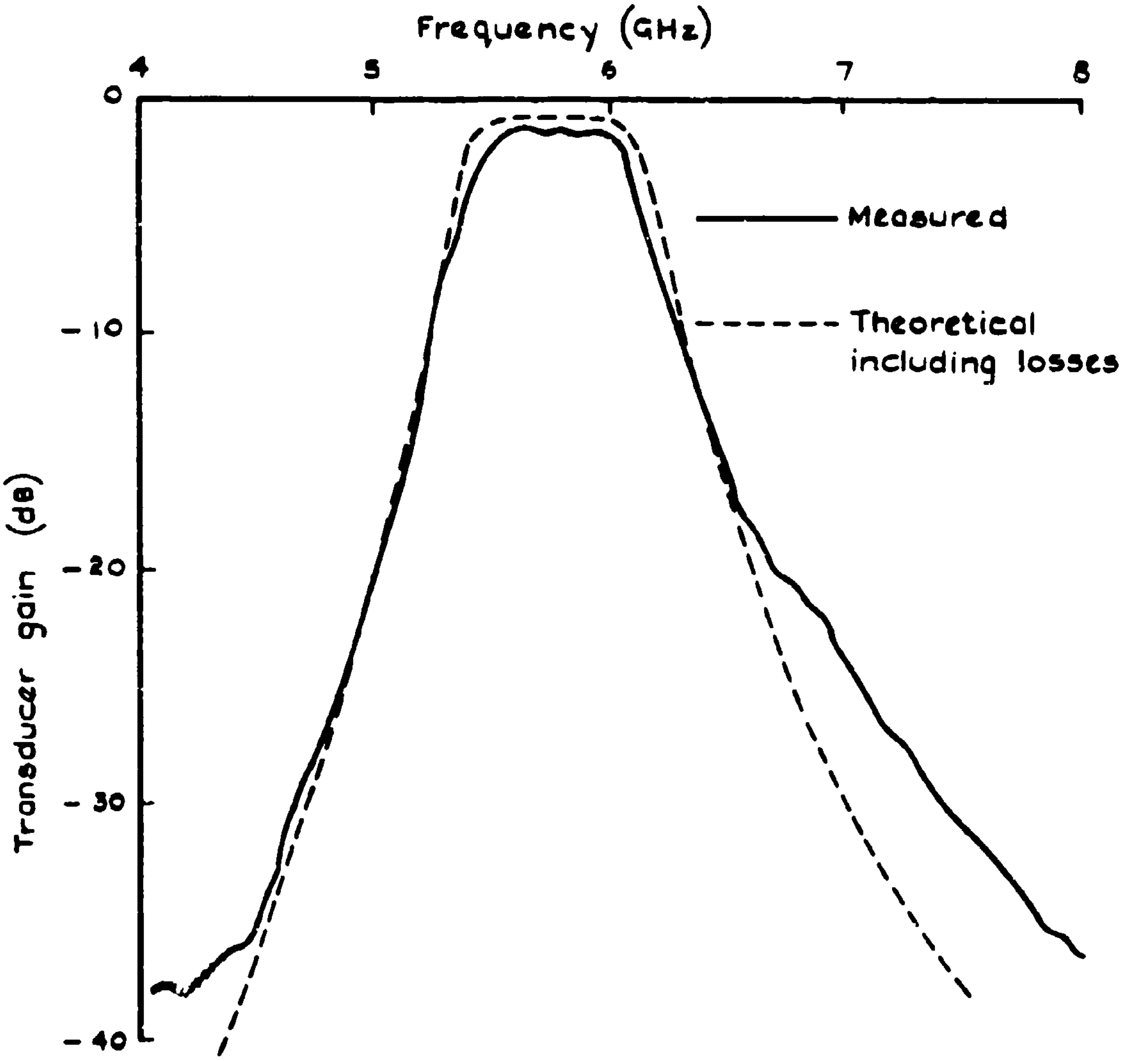


Fig. 24 Frequency response of filter C

TR 74068

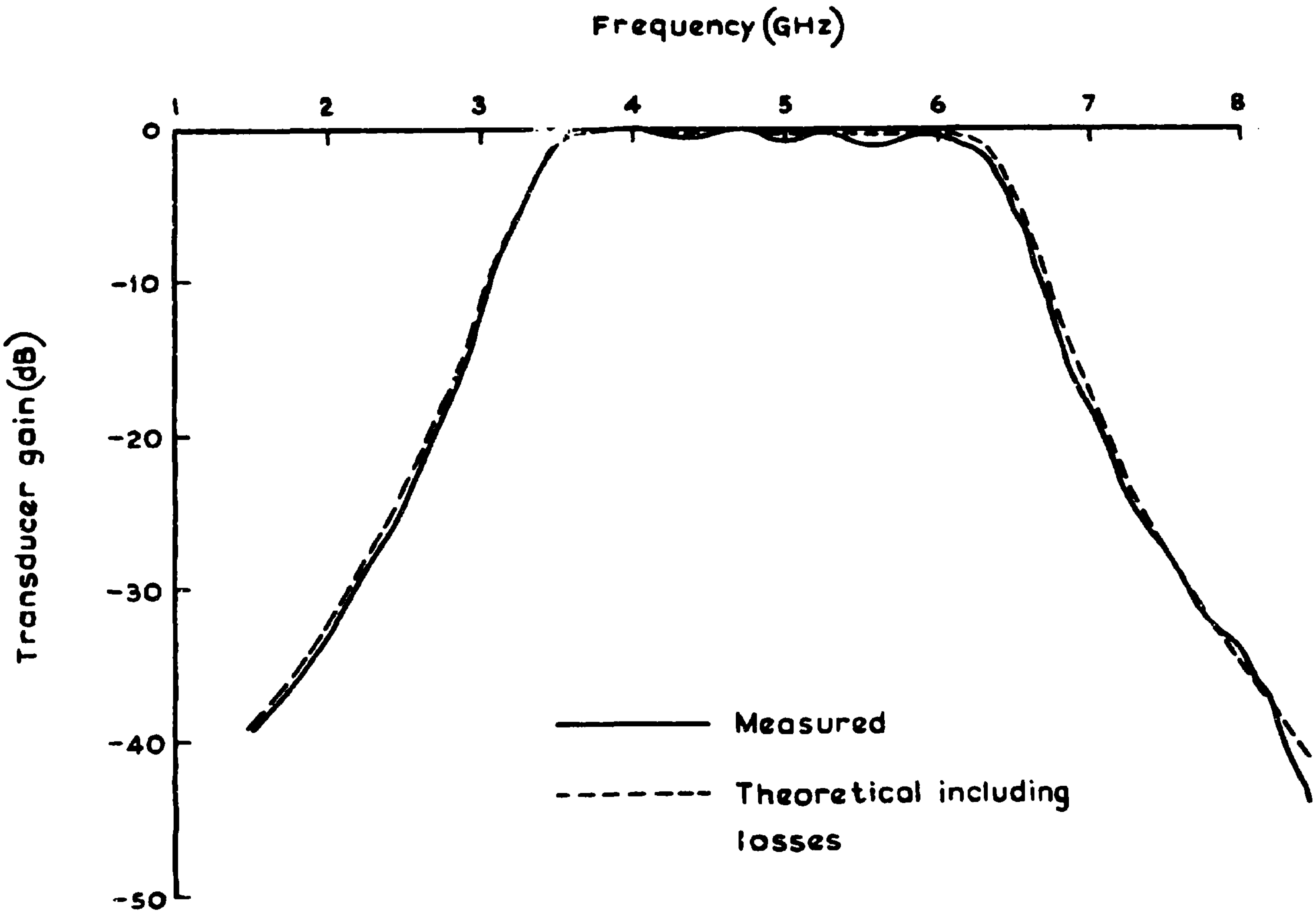


Fig. 25 Frequency response of filter D

Fig. 26

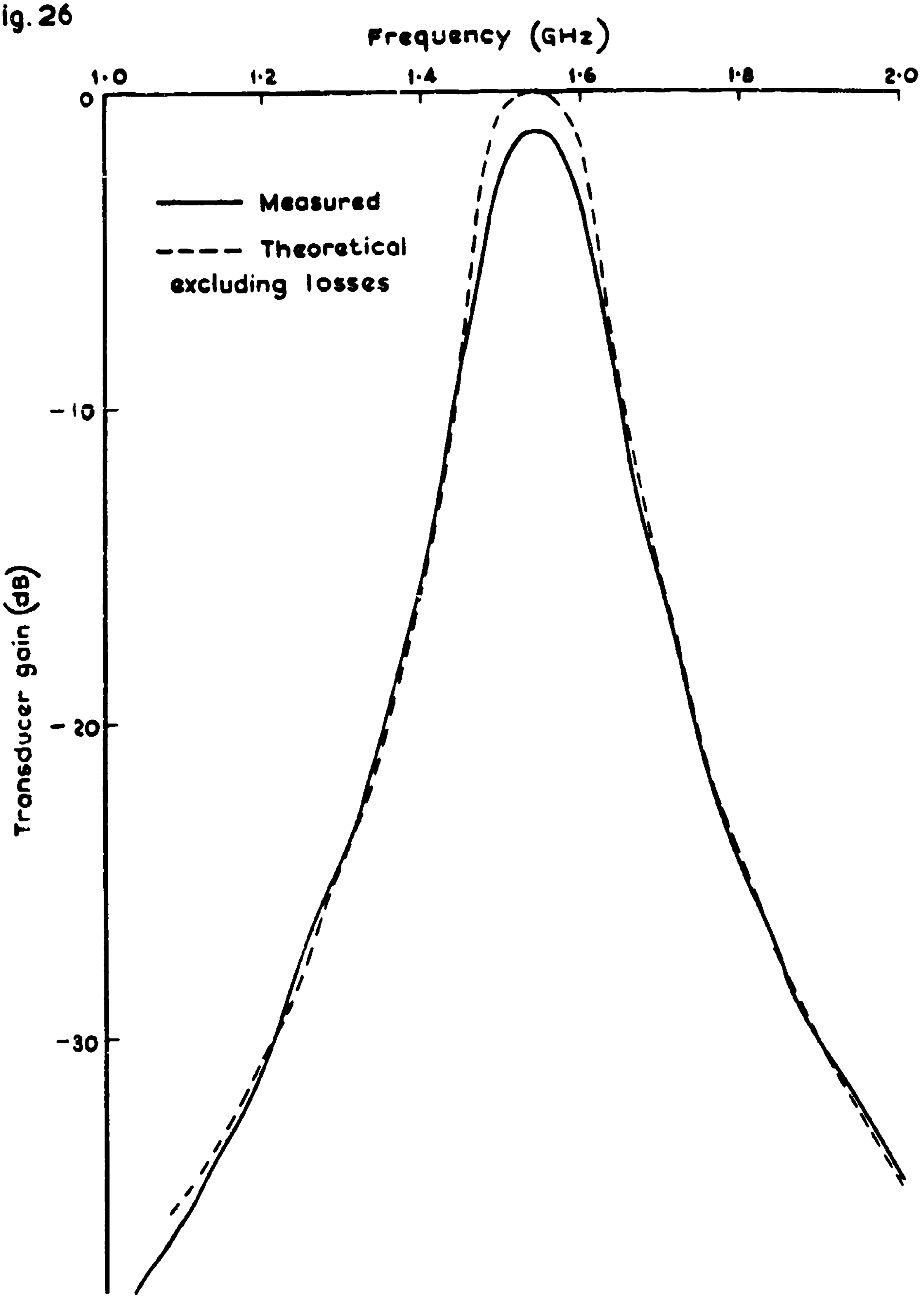


Fig. 26 Frequency response of filter E

TR 74068

Fig.27

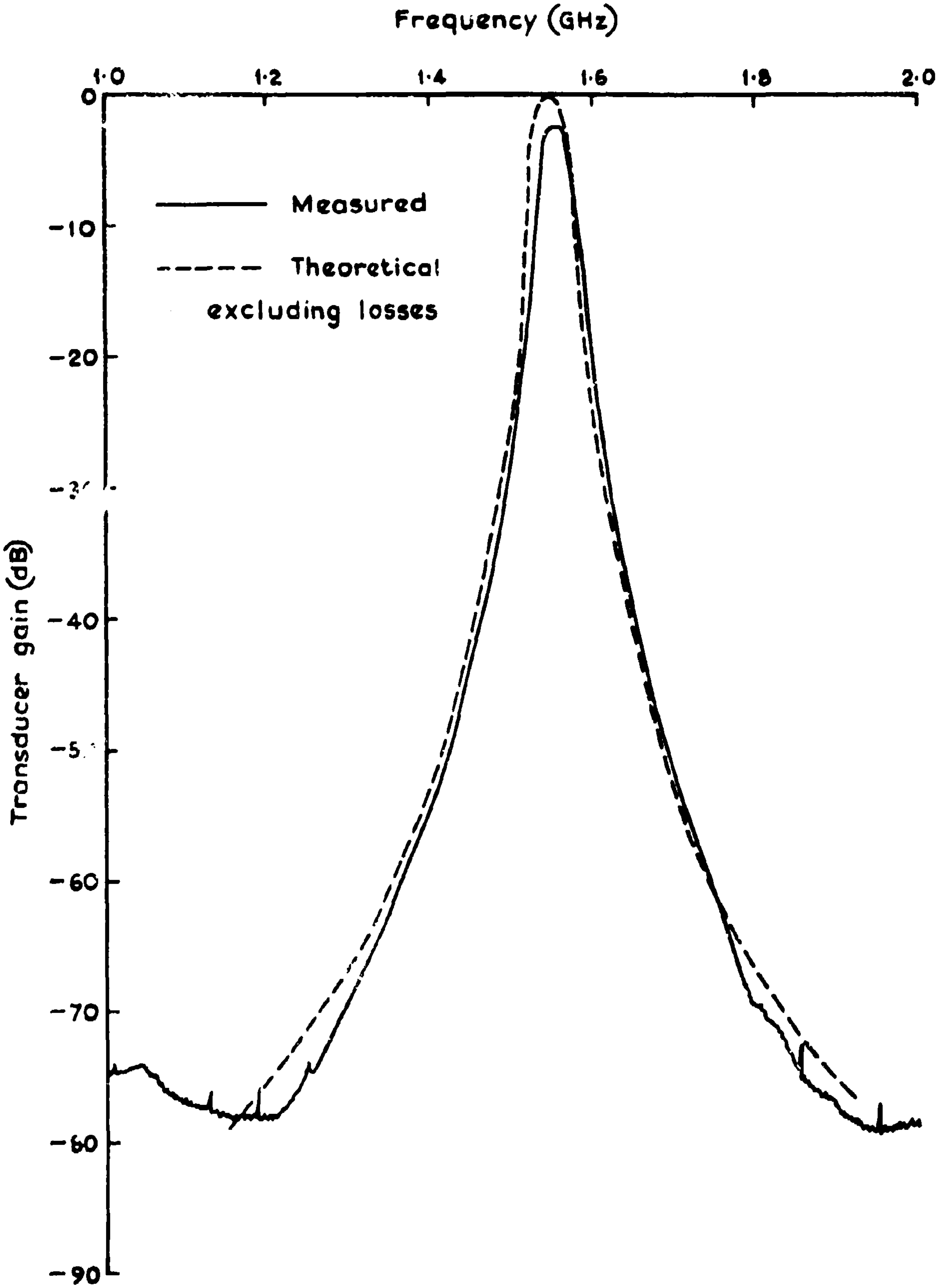


Fig.27 Frequency response of filter F

Fig.28

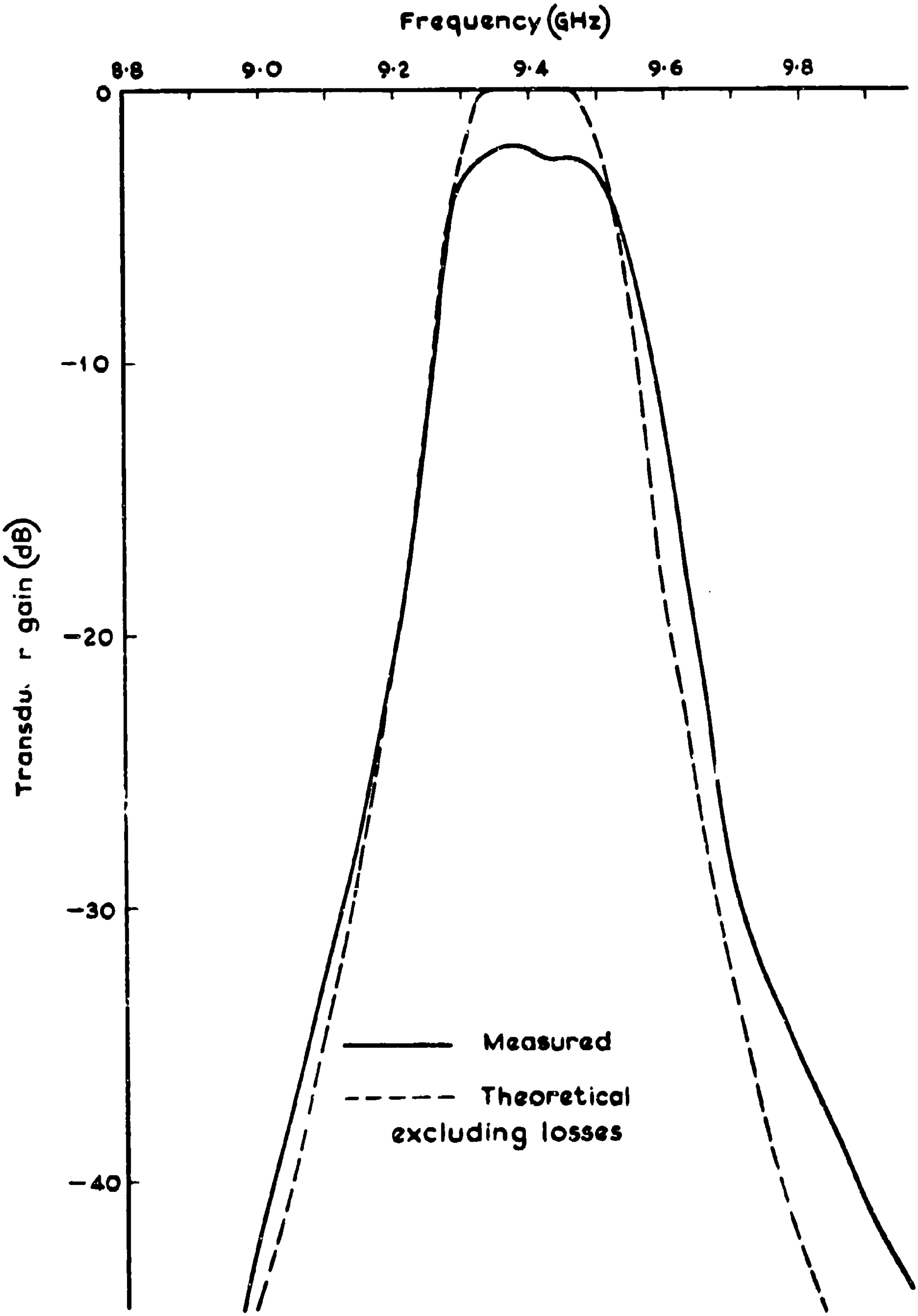
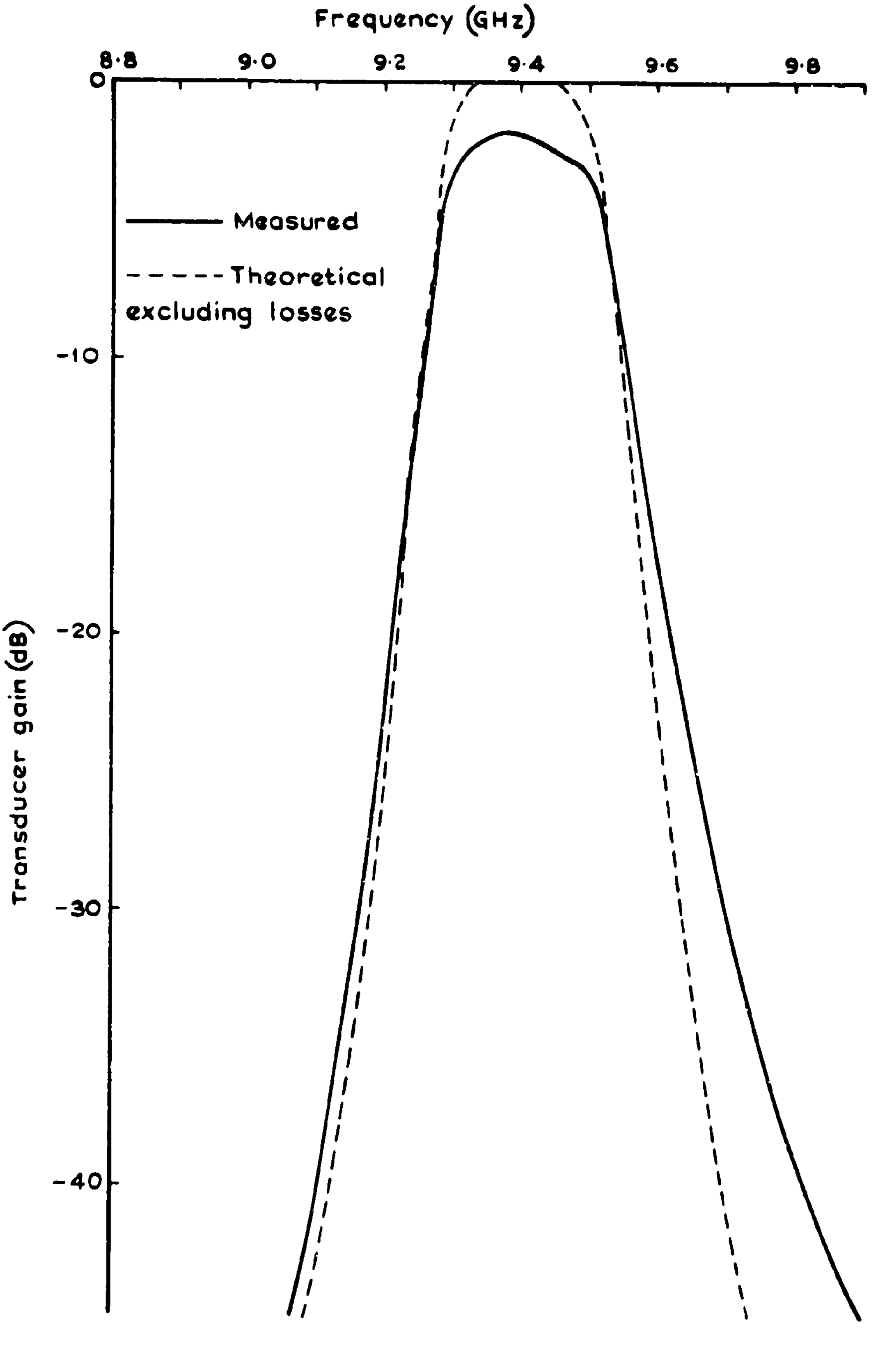


Fig.28 Frequency response of filter G

TR 74068

Fig. 29



TR 74068

Fig. 29 Frequency response of filter H

Fig. 30

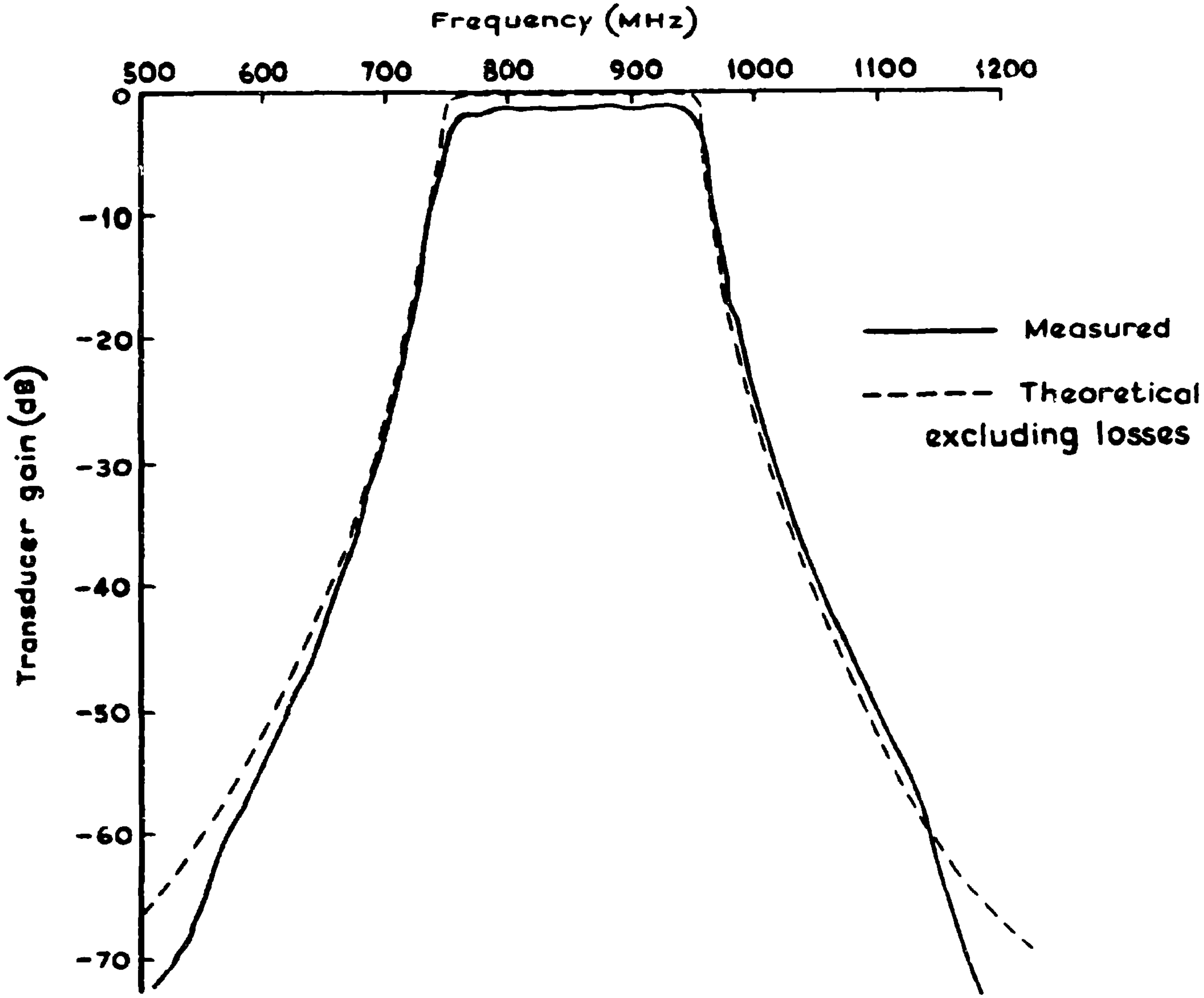


Fig. 30 Frequency response of filter I

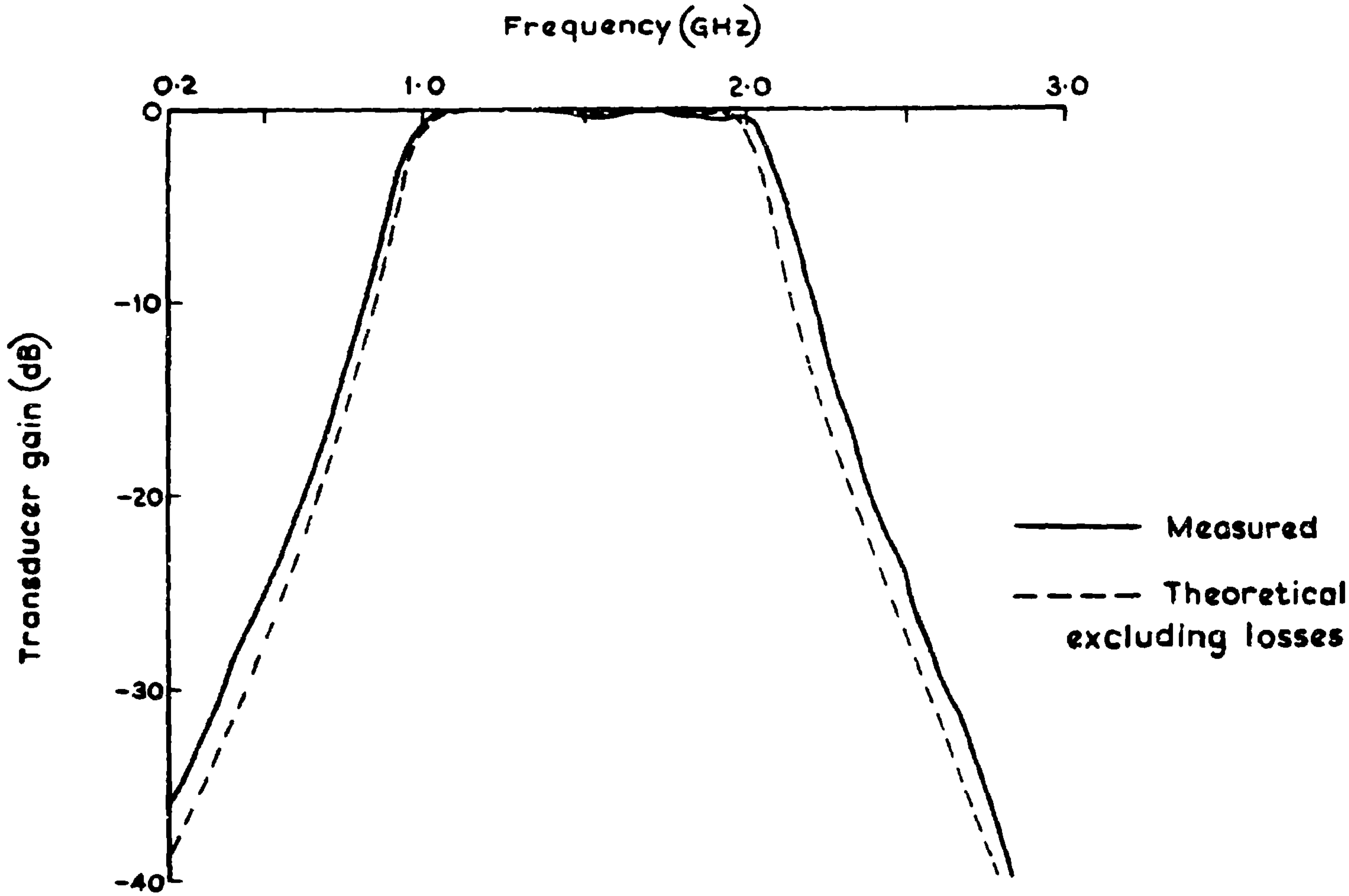


Fig. 31 Frequency response of filter J

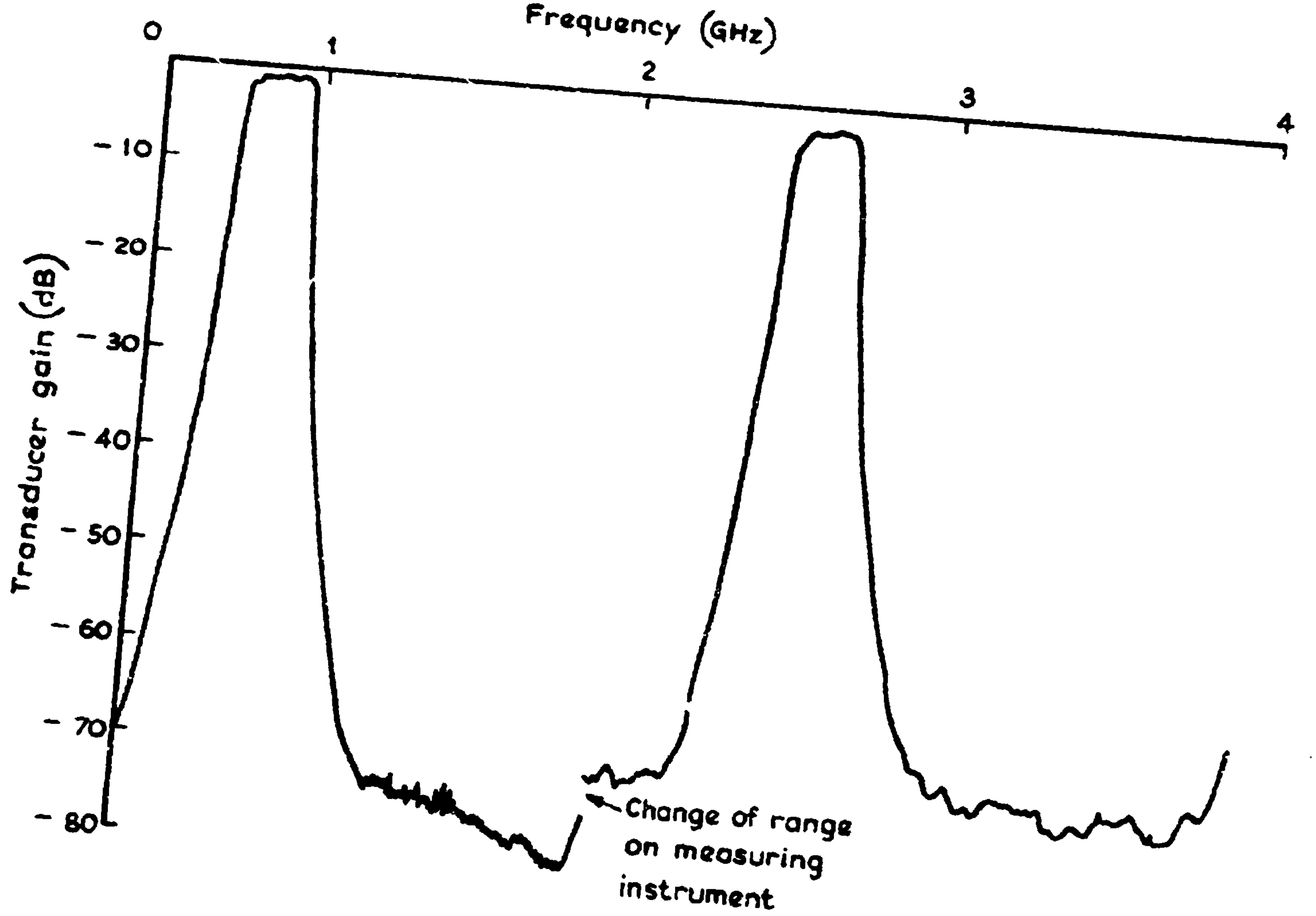


Fig.32 Frequency response of filter I over extended frequency range